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OCTOBER 1921

SOCIETY OF AUTOMOTIVE ENGINEERS INC.
29 WEST 39TH STREET NEW YORK

PLAIN bearings have been in use for centuries and except for the development of the materials of which they were made, they have come down to us practically unchanged. Yet even today there is very little accurate technical data concerning the proper use of the plain bearing.

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To that end we have established a Technical Bureau, fully manned and equipped to carry on experiments and tests for the purpose of assisting manufacturers in the proper use of plain bearings.

Manufacturers are urged to submit their bearing problems to us for careful, impartial consideration.

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The chemical composition of Non-Gran approximates that of ordinary bronze. But microscopic examination shows it to have a more dense, homogeneous structure than ordinary bronzes.

That is what gives Non-Gran its remarkable resistance to wear—as its particles are not torn away by frictional drag.

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Vol. IX October, 1921 No. 4

Coming Society Meetings

THE Meetings Committee has completed its schedule of national meetings for the 1921-1922 season and is engaged in the arrangement of the program details. The activity of the Society in the meetings field is to be maintained on the same basis is in the past notwithstanding industrial conditions. The coordination of thought and effort centered in engineering meetings has an economic value that cannot be measured readily, but is recognized as an important factor in our industrial and national life. Times like the present accentuate this value and the Council and the Meetings Committee plan to maintain a more aggressive policy than ever before to make the coming sessions of the greatest possible benefit to the members and the whole automotive field.

Visit to Aberdeen Proving Ground

General Williams' invitation to the Society to visit Aberdeen Proving Ground will be accepted by a great many members. The Metropolitan, Pennsylvania and Washington Sections are making this event the occasion of their October gatherings, and a number of members from more distant points have signified their intention of being present.

The program will fill the entire day and consist of firing tests and demonstrations of guns, armor-plate, projectiles, aerial bombs, aircraft, machine-guns and mobile mounts. The Army Ordnance Association will hold its annual convention at this time and members of the American Society of Mechanical Engineers interested in ordnance development have been invited to attend. There will, therefore, be present a most notable group of those to whom the Army will look for engineering cooperation in the event of need. On Saturday, Oct. 8, the Society's Ordnance Advisory Committee will hold a session at the office of the technical staff of the Ordnance Department in Washington.

At Aberdeen, beginning at 9:40 a. m. Friday, Oct. 7, and until 8 in the evening, every minute will be filled with interesting events. The program will be substantially as follows:

(1) Firing of tracer ammunition from Browning machine-guns against free balloons
(2) Firing of new design 0.50 caliber machine-gun
(3) Firing of mobile guns varying from 75 mm. (2.95 in.) to 9.20 in. in caliber, mounted on various types of carriage
(4) Demonstration of 75-mm. (2.95-in.) gun and 105-mm. (4.13-in.) howitzer on Christie motor carriages with removable tracks
(5) Demonstration of 75-mm. (2.95-in.) gun and 105-mm. (4.13-in.) howitzer on Holt motor carriages that it is claimed can make 30 m.p.h.
(6) Demonstration of tractor-drawn gun cariages versus self-propelled carriages
(7) Demonstration of 155-mm. (6.102-in.) gun or 8-in. howitzer Mark IX Holt motor carriage
(8) Demonstration of 3.7-in. anti-aircraft gun on Christie mount
(9) Demonstration of 4.7-in. anti-aircraft gun on Christie mount
(10) Demonstration of 2½, 5 and 10-ton caterpillar tractors
(11) Demonstration of Peoria reconnaissance tractor
(12) Demonstration of Militor truck equipped with Chase track
(13) Demonstration of Dodge truck equipped with Chase track
(14) Demonstration of small, medium and large tanks
(15) Dropping of 2000 and 4000-lb. bombs from airplanes. This is one of the main features of the program
(16) Dropping of 600-lb. bombs with instantaneous functioning and with delay-action fuses. This is one of the main features of the program
(17) Examination of collection of foreign ordnance materiel, including 42-cm. (16.5-in.) German howitzer
(18) Examination of mobile ordnance-repair-shops
(19) Demonstration of machine-gun firing from airplanes. This demonstration will be made on the grounds at the aviation field and show the operation of the synchronizing device that permits firing through the propeller
(20) Exhibition of all types of United States and foreign bombs
(21) Exhibition of various types of airplane adapted to carrying bombs
(22) Exhibition of the C-2 dirigible airship
(23) Firing of 16-in. 50-caliber gun from barbette mount. This feature of the program is very unusual
(24) Firing of 16-in. 50-caliber gun from disappearing mount
(25) Examination of armor-plate that has been pierced by projectiles
(26) Examination of projectiles that have gone through armor-plate
(27) Examination of instruments used in obtaining the

velocity of projectiles that utilize the making, breaking or inducing of an electric current
(28) Firing of 14-in. railroad mount

There will be a 1-hr. intermission for luncheon and the demonstrations will be concluded in time for dinner, after which a smoker will be held and a number of short talks given.

It will be necessary for the Commanding Officer to engage an outside caterer to provide luncheon and dinner, the combined cost for which will be, it is estimated, about $3. Members who intend to be present should notify the Commanding Officer, Aberdeen Proving Ground, Aberdeen, Md., at once, in order that he may make the necessary mess arrangements. A check for $3 should accompany the letter. As a definite guarantee must be given to the caterer, no meals will be provided except for those who have previously notified the Commanding Officer.

Army regulations provide that admission to the Proving Ground be limited to citizens of the United States, excepting those who are engaged in the manufacture of munitions for foreign governments which are at war. As a means of identification and a pass to secure entrance into the reservation, members are requested to wear upon their arrival at Aberdeen and throughout the period of the meeting a tag that will be sent upon application to the office of the Society, 29 West 39th Street, New York City.

Special cars from New York City will be attached to the Baltimore & Ohio Railroad train leaving Pennsylvania Station at 1:00 a. m. Oct. 7. These cars will be ready for occupancy after 10:00 p. m. Thursday night. At Philadelphia these special cars will be detached and placed on the train with the Philadelphia contingent leaving at 7:45 a. m., stopping at Wilmington at 8:20 and arriving at Aberdeen at 9:10 a. m. Breakfast on the train.

A train will leave Washington at 7:45 a. m. and Baltimore at 8:40 a. m., arriving at Aberdeen at 9:24 a. m.

In the evening a train will leave Aberdeen at 8:37, reaching Wilmington at 9:25 p. m. and arriving at Philadelphia at 10:00 p. m. It will be possible to reach New York City late this same evening, depending somewhat upon train connections in Philadelphia.

A train will leave Aberdeen at 8:26 p. m., arriving at Baltimore at 9:03 p. m. and Washington at 10:05 p. m.

A number of members will probably drive to Aberdeen and they should arrange to be there at a time not later than the arrival of the trains.

Due to the lack of suitable facilities, it will be impossible to include ladies in this trip.

The Annual Meeting

The Annual Meeting of the Society will be held at New York City, Jan. 11-14, 1922, during the week of the New York Automobile Show. This arrangement is in accordance with precedent and is based on the knowledge that a large number of the members come East to visit the Show and study the exhibits. Sessions of the Standards Committee will be held on the morning and afternoon of Tuesday, Jan. 11. Many interesting and important reports are to be presented and discussed preparatory to their submission to the members for letter ballot on the adoption of standards and recommended practices. The technical session devoted to aeronautics will be held Tuesday evening, when it is proposed to have papers read on the latest engineering developments in this field. Reports of the executive officers for the year 1921 will be presented at the business meeting, Wednesday morning, and the result of the ballot for the election of officers for 1922 announced. Immediately following this H. M. Crane, chairman of the Research Committee, and Dr. H. C. Dickinson, will address the members on the work of the recently organized Research Department.

The broadened field of the Society's work necessitates the continuance of the holding of simultaneous sessions on those automotive engineering subjects whose scope does not overlap. Even with this arrangement it has been considered advisable to continue the professional meetings into Friday morning in order that the most important topics can be presented adequately.

On Wednesday afternoon three meetings will be conducted simultaneously on Body Engineering, Lubrication and Commercial Vehicles. There will be only one session on Thursday morning, when the subject will be Automotive Research. The Committee hopes to have an address made at this time by an engineer of international standing outlining certain experiences in automotive research abroad that confirm the increasing faith in industrial research as a paying investment. Thursday afternoon will be occupied by simultaneous meetings on Engines and Automotive Materials. The former will include fuel as well as engine papers. It is the purpose of the materials meeting to acquaint the members with metallurgical development since the war. A Passenger-Car Session will be held Friday morning, at which the chassis-design topics of greatest engineering interest will be discussed. Among these will be brake mechanisms and brake-lining materials.

The Carnival that has endeared itself to the members of the Society will be held on Wednesday evening, Jan. 11, starting at 10:30 p. m. The features of this event will be held in secret status by the committee as in the past. The element of surprise has proved an essential factor in past successes and for this reason the arrangements will not be disclosed beforehand.

The Annual Dinner has been set for Thursday evening, Jan. 12, and will at least maintain the standard of past years that has made this occasion institutional in character. C. F. Kettering gave his promise last January to repeat as toastmaster and our members appreciate the fact that this insures a lively evening.

Chicago Meeting

The Chicago Meeting of the Society will be held at the Hotel Drake, Feb. 1, 1922. There will be technical meetings in the morning and afternoon devoted principally to the problems of the operation and maintenance of automotive vehicles. The Chicago Dinner will be held at the Drake on the evening of the same day.

HIGHWAYS

THE bald statement, not infrequently heard, that considering their short life and the money invested in them, our new highways are economic failures, is, of course, untrue, but it contains enough of the truth to challenge our serious consideration and our best efforts to make it groundless in the future. Within certain limitations we should be able and the public may reasonably expect us to design and construct highways with something like the same success and certainty of results that characterizes our work in other departments of engineering.—S. Whinery.

Methods of Gear Design and Gear-Cutting

By GLENN MUFFLY[1]

CLEVELAND SECTION PAPER *Illustrated with* PHOTOGRAPHS AND DIAGRAMS

AFTER mentioning primitive forms of gears and stating the necessity for developing a tooth curve that would transmit uniform motion, the author describes and illustrates the cycloidal form of tooth and then considers the method of laying out involute gear teeth, this form having been adopted so that a constant pressure-angle or straight-sided form of rack tooth might be used.

The two methods of specifying gear-tooth sizes are illustrated and described, followed by a detailed discussion of the subjects of gear-hobs and gear-hobbing. Helical and worm gears are considered in similar style, inclusive of helical and worm-gear calculations and the hobbing of helical and worm gears. Numerous illustrations relating to each subject are presented and the paper is concluded by a brief description of ring-type thread-milling, which is sometimes confused with gear hobbing.

IN considering any pair of gears, the pitch cylinders or cones which represent the real line of their action must be kept in mind. Two plain cylinders, rolling in contact with each other, could not transmit much power; so, teeth of some kind must be provided. Fig. 1 shows what our grandfathers called "cog wheels." The cogs originally were cast or cut out with a chisel, and roughly smoothed up with a file. These cogs or teeth

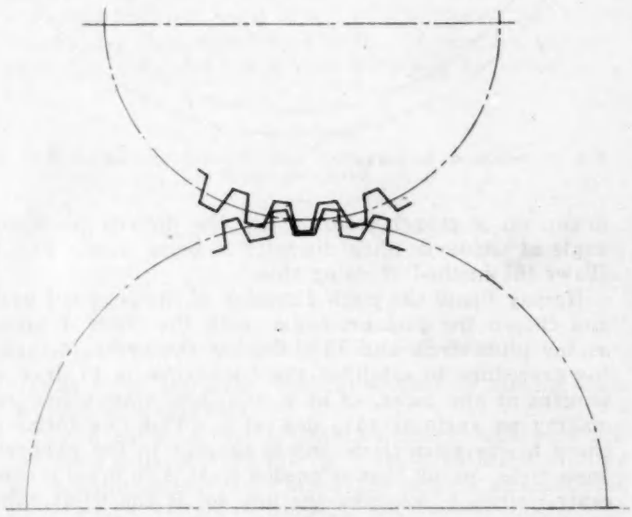

FIG. 1—AN EARLY FORM OF "COG WHEELS"

prevented slippage and insured a positive ratio of revolutions between two shafts, but there was no uniformity of action. The teeth had no special form; they merely had clearance. These primitive gears succeeded in turning around on time, but they moved intermittently. As

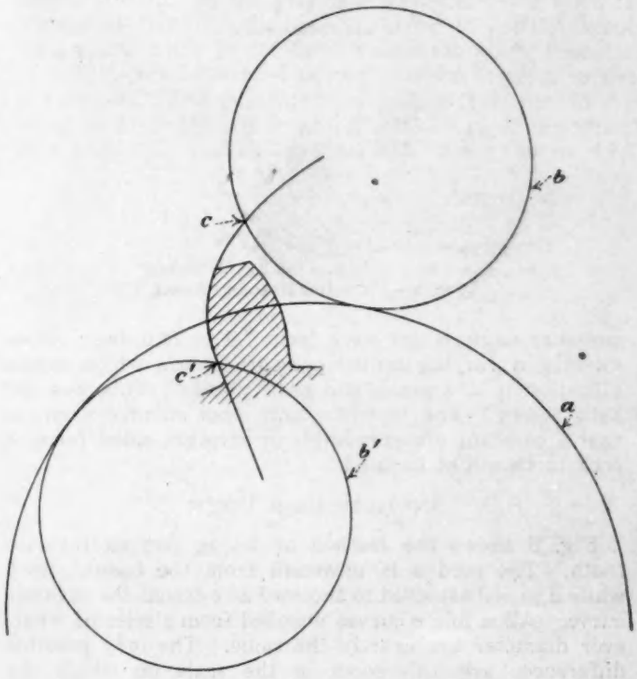

FIG. 2—THE CYCLOIDAL FORM OF TOOTH

speeds became higher, it was found necessary to develop a tooth curve that would transmit uniform motion.

Fig. 2 shows the cycloidal form of tooth. The circle *a*, representing the pitch cylinder of the gear, is used as a path on which to roll the smaller circle *b* and the path of the point *c* describes the tooth-form outside of the pitch-circle. The path of the point *c'*, on the inner circle *b'*, describes the curve used for the dedendum of the tooth. A cycloidal rack tooth is shown in Fig. 3. It is the same tooth shown in Fig. 2, except that it has a straight pitch-line. A circle is rolled on one side of the pitch-line to develop the addendum curve, and a similar circle on the opposite side for the dedendum curve. Fig. 4 shows two cycloidal gears meshing together. Between these two gears the imaginary rack line is seen which is the basis of the principle of two gears rolling together. It can be shown that each gear meshes correctly with the rack and, since the rack is symmetrical, the two gears must mesh correctly with each other. The difficulty with this form of gear is that the pressure-angle varies at different points of contact. The point of contact between the gear teeth will come on the imaginary rack line and the direction of pressure will be at right angles to this rack tooth. Since the rack tooth is a curve, the line of pressure at right angles to the rack tooth will fall at various angles. The center pressure between the two gears as they rotate depends upon that angle. The

[1]M. S. A. E.—Sales manager, Lees-Bradner Co., Cleveland.

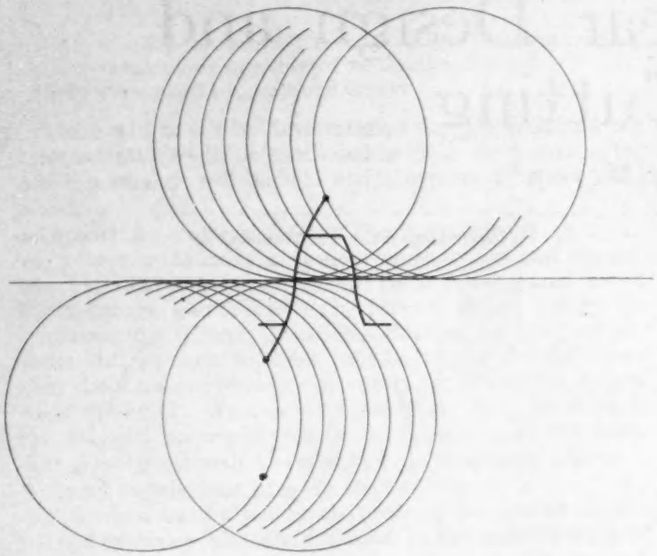

FIG. 3—A CYCLOIDAL RACK TOOTH

pressure angle might vary from 7.5 to 18.0 deg.; consequently, a varying center pressure occurs which causes vibration in the gears and their shafts. This was not satisfactory. The involute tooth was adopted then, so that a constant pressure-angle or straight-sided form of rack tooth might be used.

INVOLUTE GEAR TEETH

Fig. 5 shows the method of laying out an involute tooth. The cord *a* is unwound from the base-circle *b* while a pencil attached to the cord at *c* traces the involute curve. All involute curves unrolled from circles of whatever diameter are exactly the same. The only possible differences are differences in the scale on which the curve is drawn or differences between various parts of the same curve. Taking the circle *d* as the pitch-circle and constructing a tooth, it will be found that it has a pressure-angle of say 20 deg.; going farther out on the curve and constructing another tooth, as at *e*, there would be a much greater pressure-angle, as on the Maag gear; going still further and establishing a pitch-circle at *f*, the pressure-angle becomes so great as to be prohibitive on account of the excessive pressure developed between the centers of the gears. The pressure-angle is dependent upon the ratio between pitch diameter and base-circle diameter. In practice, there must be a means of establishing this ratio so that the involute curve can be drawn on a proper scale to get the desired pressure-angle at whatever pitch diameter is being used. Fig. 6 shows the method of doing this.

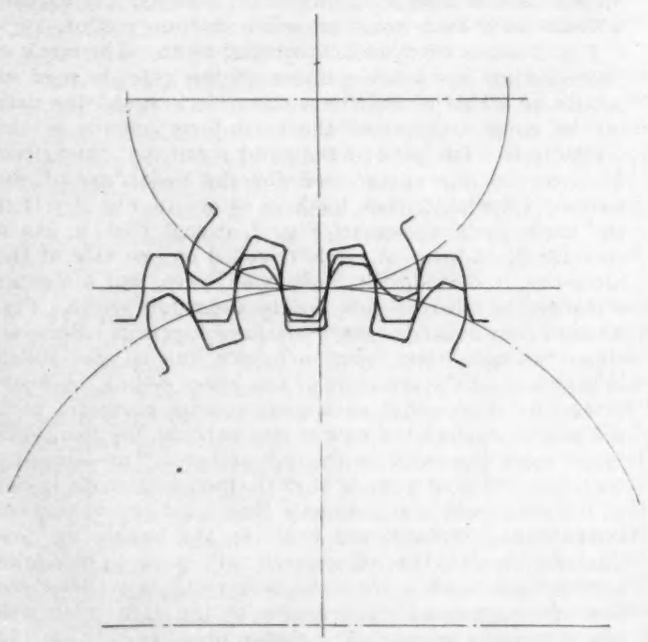

FIG. 4—DIAGRAM SHOWING THE MESHING OF TWO GEARS WITH CYCLOIDAL TEETH

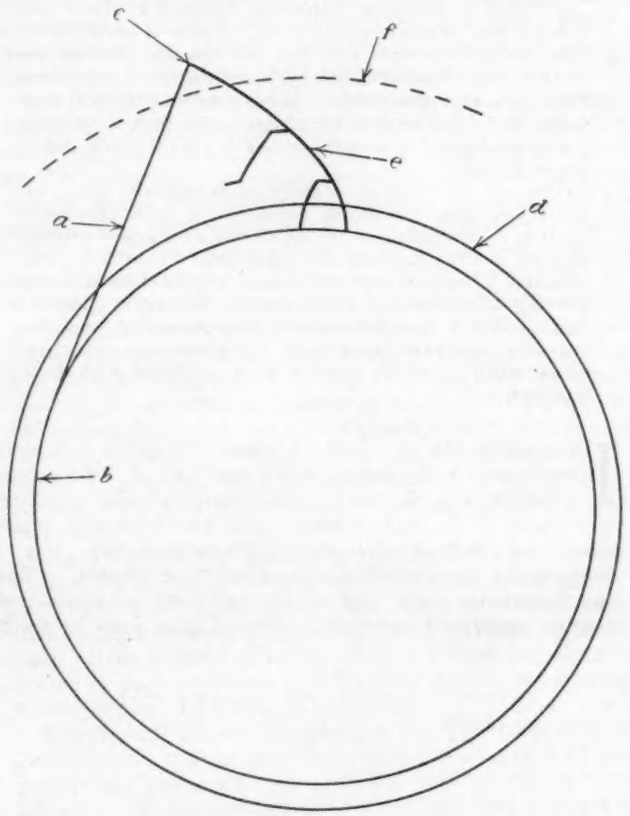

FIG. 5—DIAGRAM ILLUSTRATING THE METHOD OF LAYING OUT AN INVOLUTE TOOTH

Having found the pitch diameter of the required gear and chosen the pressure-angle, with the circle *d* taken as the pitch-circle and 14½ deg. as the pressure-angle, the procedure to establish the base-circle is to draw a tangent at any point, as at *a*, and then draw a line *aa'* making an angle of 14½ deg. at *a*. This line forms a chord to the pitch-circle and is tangent to the required base-circle; so, all that is needed then is to draw a concentric circle *b*, touching the line *aa'* at one point only. If a greater pressure-angle had been chosen, for example, an angle of 20 deg., there would have been a smaller base-circle as shown at the right by *b'*. The base-circle is always smaller than the pitch diameter, although it is usually larger than the bottom diameter of the gear. After having found the base-circle, which is dependent upon the pressure-angle desired, a cord which is wrapped around the base-circle is unwound as was explained for Fig. 5. The path of the pencil at the end of that cord describes the involute curve on a proper scale.

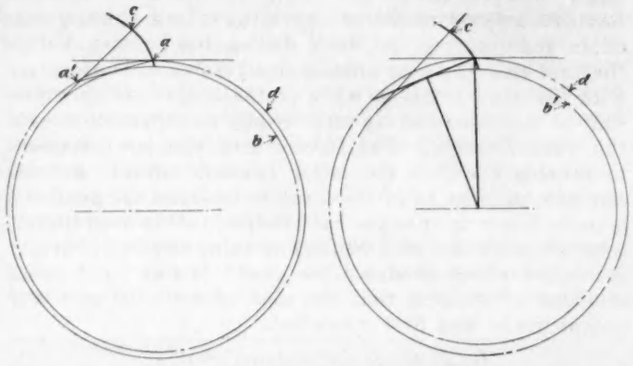

FIG. 6—DIAGRAM SHOWING THE METHOD OF DRAWING THE INVOLUTE CURVE TO GET THE DESIRED PRESSURE-ANGLE

Since the involute curve is designed to mesh with a rack, it should be possible to draw a rack by the same method that is used to draw a tooth on a gear, as in the case of the cycloidal tooth. Fig. 7 shows a straight-sided involute rack drawn in this manner. Starting with the pitch-line *d*, which is in this case a straight line, the rules for laying out an involute curve are followed. The straight line *d* can be considered as an arc having an infinite radius. Selecting a point *a* and drawing a tangent to the arc of infinite radius, it will be found that the tangent coincides with the line *d*. Then the line *aa'* is drawn, which will be found to be of infinite length. It is therefore an infinite distance from the pencil at the end of the cord to the base-circle, and the path of the point *c* will be a straight line at right angles to the line *aa'*, or at 14½ deg. from the perpendicular to the pitch-line. This is working from the involute curve back to the straight-sided tooth of the rack, but the rack is really the starting point, since it is desired to find a tooth curve that would not only give a uniform angular velocity, but a constant pressure-angle. In other words, a curve is desired that will mesh with a straight-sided rack tooth instead of with a curved-rack tooth. In practice, the rack with straight-sided teeth can therefore be taken as a

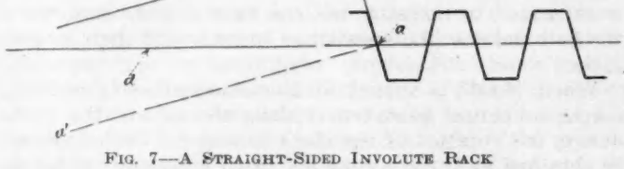

FIG. 7—A STRAIGHT-SIDED INVOLUTE RACK

master form and gear teeth generated by rolling them in mesh with this rack.

Fig. 8 shows a pair of involute gears, each of which has been generated by rolling in mesh with the involute or straight-sided rack. Since the rack is symmetrical, these gears will mesh properly with either side of the rack or with each other. In the consideration of any pair of involute gears, an imaginary rack profile can be visualized as passing between the gears as here shown. Assuming the smaller gear to be the driver and the direction of rotation as shown by the arrow, it will be found that at any point of contact between the teeth the pressure is exerted on a line at right angles to the rack profile. The pressure-angle will always be the same as the angle between one side of the rack tooth and the vertical. A 14½-deg. pressure-angle rack is therefore merely a straight-sided rack with an included angle of 29 deg. Observe the points of contact at *c*, *c'* and *c''*. Lines are drawn to indicate the direction of pressure at each point. It will be noted that these lines all pass through the point of contact between the two pitch-circles.

SPECIFYING GEAR-TOOTH SIZES

Fig. 9 shows the two methods used for specifying tooth sizes. At the left is the system of diametral pitches in common use in this country, and at the right the module system which is used in connection with the metric system. In the first case, the number of teeth is divided by the pitch diameter in inches to get the diametral pitch, while in the second case the pitch diameter in millimeters is divided by the number of teeth to get the module. The rule for transposing from one to the other is to divide either one into 25.4 to get the other. For instance, a gear of 2 module would be of 12.7

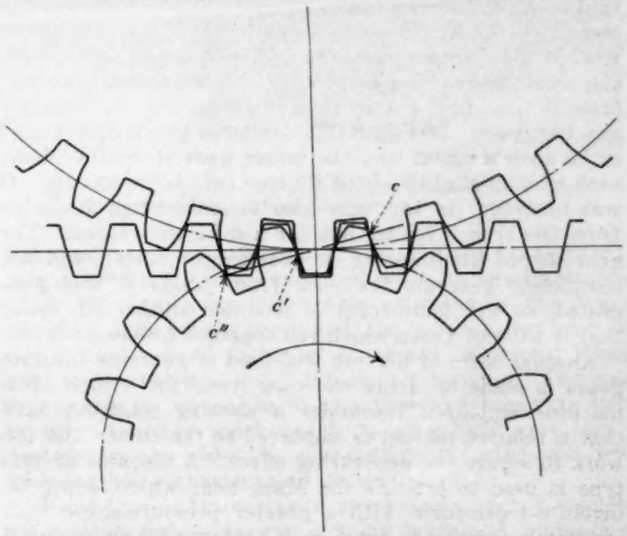

FIG. 8—A PAIR OF INVOLUTE GEARS, EACH OF WHICH HAS BEEN GENERATED BY MESHING WITH AN INVOLUTE OR STRAIGHT-SIDED RACK

diametral pitch, a 10-pitch gear would be of 2.54 module, and so on. To remember what diametral pitch is measure off 3.1416 in. on the pitch-line and count the teeth, which will be the diametral pitch. A gear of 1-in. pitch diameter has as many teeth as its diametral pitch. In the old-style single-cutter type of gear-cutter it was necessary to lay out a series of involute tooth-forms and make a series of cutters for each pitch. The tooth-forms generated by the same rack on two gears of different diameters will be different. It was customary to approximate

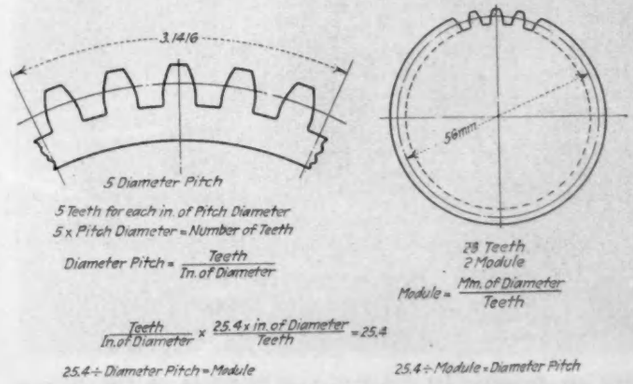
3.1416
5 Diameter Pitch
5 Teeth for each in. of Pitch Diameter
5 x Pitch Diameter = Number of Teeth
Diameter Pitch = Teeth / In. of Diameter
Teeth / In. of Diameter x 25.4 x in. of Diameter / Teeth = 25.4
25.4 ÷ Diameter Pitch = Module
50mm
28 Teeth
2 Module
Module = Mm. of Diameter / Teeth
25.4 ÷ Module = Diameter Pitch

FIG. 9—THE TWO METHODS USED FOR SPECIFYING TOOTH SIZES

these tooth-forms by the use of eight different cutters, except in cases where it was thought worth while to go to the expense of buying a special cutter for the exact number of teeth to be cut. These old-style cutters were variously known as "disc cutters," "single cutters" and "involute cutters." While these cutters were based on the involute system, they were not true involute forms because some allowances had to be made to make them cover a range of gear diameters. This system was devised by Brown & Sharpe; so, it also is called "the B & S tooth-form."

Referring again to Fig. 8, this shows the basis of the various generating methods of producing involute gears. The most primitive form was merely a planing, shaping or slotting machine, using a single planing tool. This was fed in to the desired depth and was then backed out; the gear blank then was indexed a small part of a tooth, the tool was moved a corresponding distance tangential to the work and was again fed in to depth. The tool in this case represented one tooth of the rack. The next step of progress was to use such a tool or a grinding wheel to generate a cutter in the form of a gear, and then to use this cutter as a planing tool to generate another gear. In Fig. 8, the pinion might be considered to be such a cutter and the larger gear to be the blank, each moving slightly about its own axis between cuts. It was necessary in this case also to make some deviation from the true involute, but for a different reason. The gear-shaped planing-tool, or gear-shaper cutter, will not completely generate the rack from which it was generated, so the tooth-form is modified slightly in order that it will cut gears which roll together properly.

Another form of planing tool used to generate involute gears is made by using the rack itself for a tool. The machine employed resembles a slotting machine, save that a relative motion is imparted to the cutter and the work to secure the generating effect. A machine of this type is used to produce the Maag gear which, being an involute tooth-form with a greater pressure-angle than ordinarily used, calls for a rack having a larger included angle between the teeth. Both of the last-mentioned methods employ machines operating like a slotting machine and rotating the work during the process, but in the first case the gear-shaped tool rotates in conjunction with the work rotation, while in the latter case the rack-shaped tool moves along tangentially in conjunction with the work rotation. The former is a simpler movement to provide for, but the latter machine affords a more complete generation of the involute tooth on the gear and is more direct in that the rack-shaped tool is used directly to generate the gear instead of being used to generate the cutter which produces the gear. It was right along this line of thought that the idea of hobbing spur and helical gears was first conceived.

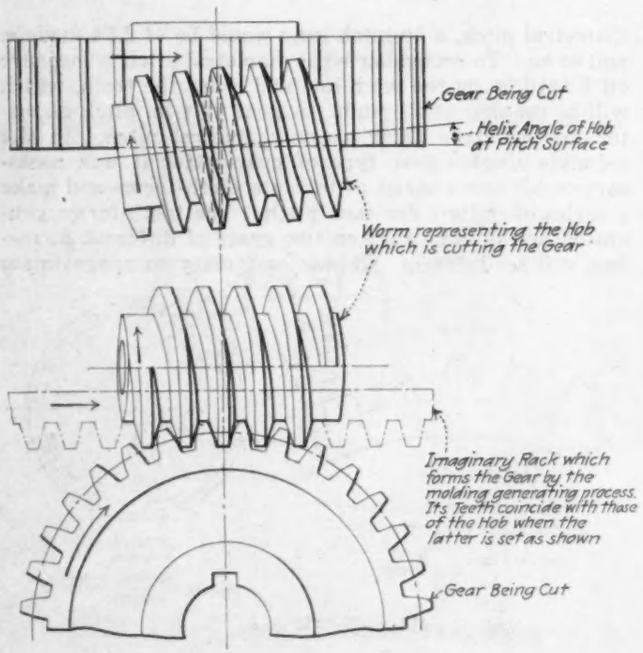
Gear Being Cut
Helix Angle of Hob at Pitch Surface
Worm representing the Hob which is cutting the Gear
Imaginary Rack which forms the Gear by the molding generating process. Its Teeth coincide with those of the Hob when the latter is set as shown
Gear Being Cut

FIG. 10—DIAGRAM ILLUSTRATING THE PRINCIPLE OF THE HOBBING PROCESS FOR FORMING SPUR GEARS

GEAR HOBS AND GEAR-HOBBING

Fig. 10 shows the principle of generating involute teeth from the rack section of a hob. The rotation of the hob provides in effect the tangential movement of the rack as indicated by dotted lines. This method is accomplished with the simpler rotary motion because that affords the more complete generation, and the gear is generated directly from the rack instead of through the medium of an intermediate generation. In addition to this, the hobbing method has the advantage of speed, since it is a continuous cut from start to finish of an arbor full of gears, as compared with reciprocating motion on any other type of gear-cutter. To bring this point out clearly, a partly finished gear is shown in Fig. 11. After going over the principles of hobbing in what seems to be a thorough manner I am sometimes asked how, after having cut through one tooth, the blank is indexed for the next tooth. It is evident from Fig. 11 that, after one tooth has been cut through, it is not necessary to index; the entire gear is finished at one traverse past the hob. The blanks rotate constantly during the process, in the same manner as in hobbing a wormwheel, but the feed is along the axis of the blanks instead of being in toward the center of the blank. The invention of the process was inspired by the older method of hobbing a wormwheel. In Fig. 10 it can be assumed that the lower view illustrates the hobbing of a wormwheel instead of a spur gear. The next step is to tilt the hob axis, as shown in the upper view, so that the teeth will be cut straight across the face of the blank instead of at an angle. Then, after the hob is fed in to the proper depth, it is caused to travel across the face of the blank while the hob and the blank continue to rotate at their proper ratio.

When "feed" is spoken of in connection with hobbing a spur or helical gear, travel along the axis of the blank during one rotation of the blank is meant. This feed can be obtained by traveling the hob or by traveling the blank. We prefer the latter, as hobbing is essentially a milling operation and in milling practice it has been found best to travel the work rather than the cutter.

Fig. 12 shows a Lees-Bradner built-up hob, in which separate racks are assembled after having been ground all over. In this hob it is easier to visualize the rack profile than in a solid hob such as is shown in Fig. 11. Solid hobs are formed on backing-off machines, giving the same relief at the bottom between teeth as at the top of teeth. Some solid hobs are ground on the sides of the teeth in backing-off machines after hardening. This eliminates the distortion of teeth in hardening and insures an accurate rack profile from which to generate the gear. Our method in making this built-up hob is to do the grinding on the sides of the teeth after hardening, but before assembling the racks in the hob body. The

advantage is that we can grind with a larger wheel and hold to closer limits. The disadvantage is that we cannot make these hobs in small diameters. In most cases where extreme accuracy is not required, we recommend the use of smaller solid hobs, even though we do not make them, for the smaller-diameter hobs give a higher production. These built-up hobs are used almost exclusively on timing-gear work, where the quietest possible gears are much to be desired.

Fig. 13 shows one of our machines cutting flywheel gears with a solid hob. On this work production is of greater importance than extreme quietness of operation; so we recommend a solid hob with multiple threads. There are about 130 teeth on this gear and the face is about 1 in. The production is 120 flywheel gears in 9 hr., which would not be possible with a single-threaded hob. The reason for the higher production of the multiple-threaded hob and the hob which is smaller in diameter is that they call for a higher speed of work rotation with the same cutter speed, measured in feet per minute. The ratio between the hob and the work rotation speeds is inversely as the ratio between the number of threads on the hob and the number of teeth in the gear that is being cut. Revolving the work at a higher speed allows cutting across more gear-face in a minute without using an excessive feed per revolution of the blank. We do not in any event recommend the use of multiple-threaded hobs for timing-gear production. Some makers are using multiple-threaded hobs for a roughing cut on timing-gears, but we believe in taking one cut only and being particular to take that one cut right. The amount of metal removed from a timing-gear does not call for two cuts if the machine is rigidly constructed.

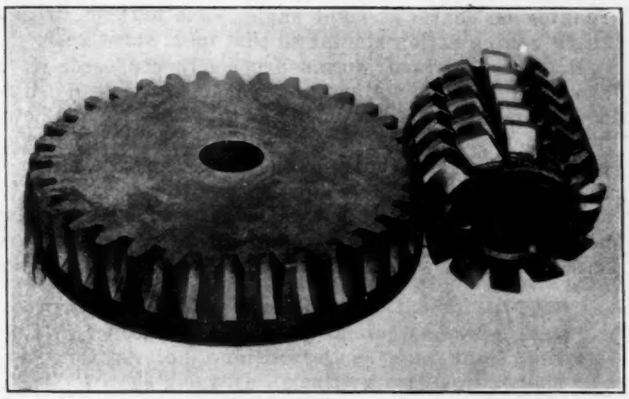

FIG. 11—RELATIVE POSITIONS OF THE HOB AND A PARTIALLY FINISHED GEAR BLANK

Regarding the amount of metal removed, another important point affects the running qualities of gears. When metal is removed from one side of the gear first, cutting some teeth entirely through before others are touched, there is a distortion of the blank. In the hobbing process metal is removed uniformly from all sides of the blank. This is important in view of the expansion of the blank from the heat of the cut. When the first tooth is cut in a cold blank and the last tooth cut in a heated blank, there is a difference in the depth of the teeth. Metal will distort under stress or heat and on an operation so important as gear-cutting these facts should be borne in mind. It is frequently thought, for instance, that a transmission gear is too heavy to distort and will support itself on the arbor during the cut.

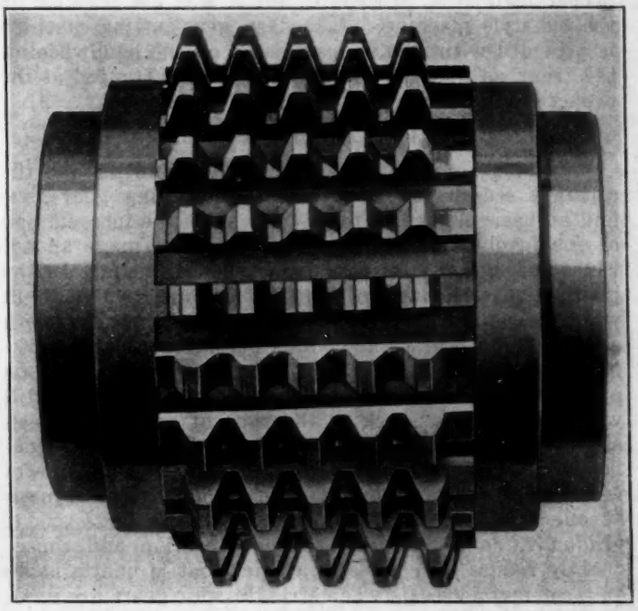

FIG. 12—A BUILT-UP HOB IN WHICH SEPARATE RACKS ARE ASSEMBLED AFTER BEING GROUND ON ALL SURFACES

This may have been all right on the old-style gear-cutting machine with its single cutter at work on one tooth, because the blanks were probably as rigid as the overhanging arm which supported the work arbor and it would have seemed to be out of reason to support them with plates, but it is much different in hobbing. The hob is working on several teeth at a time and removing two or three times as much metal; methods that were satisfactory on the old-style gear-cutting machine will not give the hob a chance to do its best work.

While tractor transmission gears appear heavy enough to support themselves when being machined, plates are necessary to clamp them on the work arbor. The same thing was true of the flywheel-gear job shown in Fig. 13. When the gears have been finished, the hob is backed out of engagement with the gear teeth, preparatory to removing the finished gears from the machine. This is the

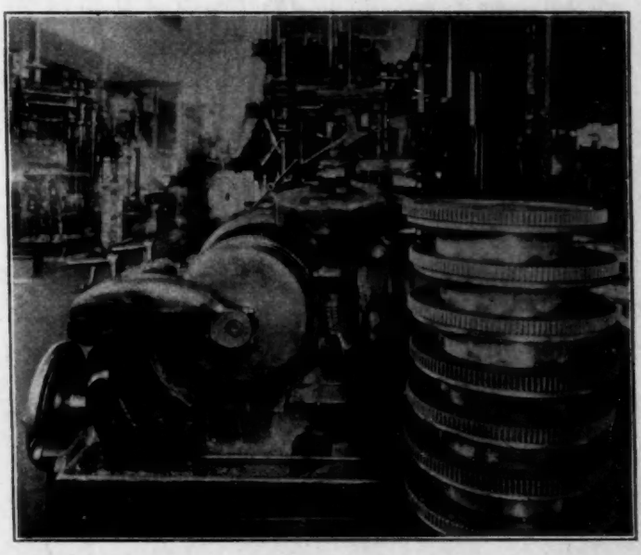

FIG. 13—FLYWHEEL GEARS BEING CUT BY A SOLID HOB AT THE RATE OF 120 GEARS IN 9 HR.

proper method of procedure, but it was not possible on the old-style machine. A modern gear-cutting machine is provided with a micrometer stop on the handwheel at the front, so that the hob is automatically stopped at the proper depth for the next arbor full of gears.

Helical and Worm Gears

Referring again to the subject of tooth-forms and the constant search for more smoothly running gears, we find no basic change of tooth-form since the introduction of the involute tooth. We have, however, made an advance through the introduction of helical gears. In the pair of gears shown in Fig. 8 there are two teeth in working contact at the points c and c'. When two teeth engage they make a line contact across the entire working face of the gear. If this pair of gears could be produced with absolutely perfect tooth curves, there still would be a slight shock at the time of contact between any two teeth because those already in action are deflected slightly by the load they carry. It would therefore be an obvious advantage to have more teeth in mesh at one time, or to have them come into engagement gradually, so as to decrease the vibration and consequently reduce gear noise to a point that is unattainable on a commercial basis when straight spur gears are used.

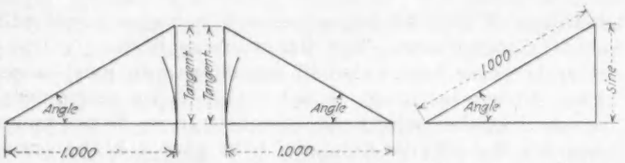

Fig. 16—Right-Angle Triangles Used To Enable the Student To Identify the Relations between the Angle opposite the Right Angle and Its Tangent and Sine

The solution of this problem is to cut the teeth in helical form instead of parallel to the axis of the gear. This is the reason for the universal adoption of helical timing-gears in place of spur gears. Helical gears are ordinarily thought of as being in the two classes of those which operate on parallel shafts and those which operate on shafts at some other angle, usually at a right angle.

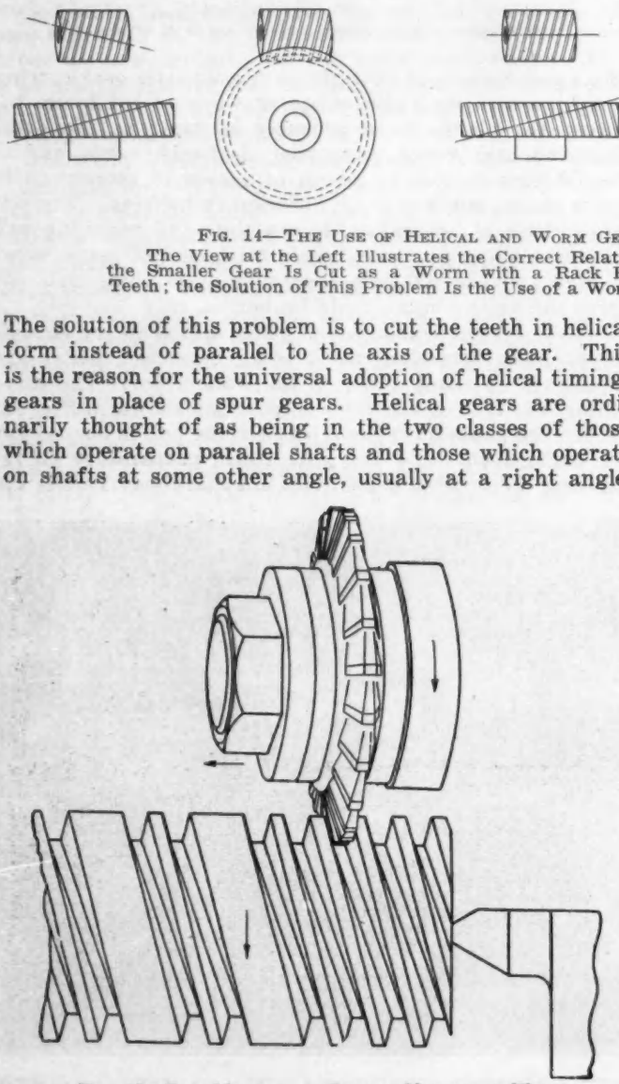

Fig. 15—The Method of Thread-Milling a Worm

There is, however, no difference between these two types so far as the cutting of the gears is concerned. Gears running on parallel shafts roll together with a slight sliding action like that of spur gears, and helical gears running on shafts at right angles slide together with a slight rolling action similar to that of a worm gear.

Helical gears and worms are easily confused, as is shown in Fig. 14. A pair of helical gears designed to operate on shafts at right angles to each other is shown at the left. If a standard involute rack of the proper pitch were engaged with first one and then the other of these gears, it would be found that the rack must lie along the line indicated at right angles to the teeth. Any method of generation to produce these gears would be based on a rack with its profile in a plane at right angles

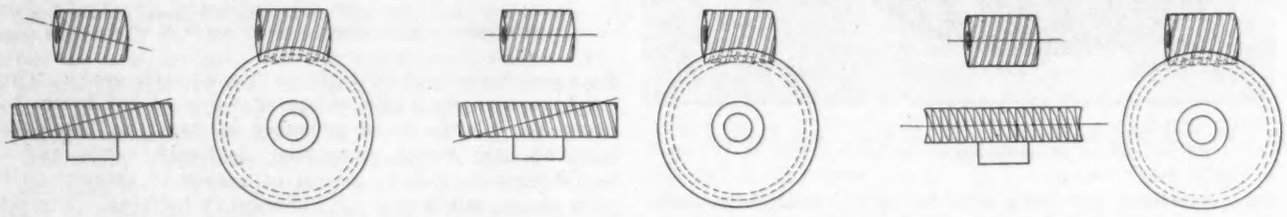

Fig. 14—The Use of Helical and Worm Gears on Shafts at Right Angles to Each Other
The View at the Left Illustrates the Correct Relative Positions of a Pair of Helical Gears; in the Central View the Smaller Gear Is Cut as a Worm with a Rack Profile along Its Axis Instead of at Right Angles to the Teeth; the Solution of This Problem Is the Use of a Worm and Wormwheel as Shown at the Right

to the tooth under consideration. If we were to lay out the involute curve, we would work from a base-circle in this plane; that is, normal to the tooth. When these two gears are meshed together, these two lines coincide. It can be said that the base-circles fall in the same plane or that the direction of rack movement is the same. Taking an imaginary rack profile and allowing it to pass through between the two gears, as was done in Fig. 8, it will be found that the direction of rack movement is normal to the teeth; that is, at right angles to them.

What appears to be the same pair of gears is illustrated in the central portion of Fig. 14, but in this case the smaller gear is cut as a worm; that is, it has a rack profile along its axis instead of at right angles to the teeth. It is obvious that when this pair is meshed together the base-circles will not fall in the same plane. A worm of the proportion shown can be thread-milled in less time than a helical gear of the same specifications can be hobbed. The solution of this problem is to use the worm in conjunction with a wormwheel as shown at the right of Fig. 14. This is a worm and wormwheel such as might be used in a steering-gear. The worm is thread-milled with a straight-sided cutter, giving it practically a rack profile along its own axis, and the wormwheel is hobbed with a hob similar in form to the worm, although preferably it is slightly larger in diameter. The longitudinal section of the hob represents the rack which generates the wormwheel. When this worm and wormwheel are meshed together, the directions of rack movement coincide. In addition to effecting a saving of time in the production of the worm, a wormwheel of these

proportions can be hobbed in less time than it can be hobbed as a helical gear.

Another fact regarding worm gears is often misunderstood. Assuming that the wormwheel shown at the right of Fig. 14 has 36 teeth and that the axial pitch of the worm is ⅓ in., this means that the pitch circumference of the wormwheel is 36 times ⅓ in., or 12 in. The pitch diameter of a gear is that diameter at which the circular motion of the gear equals the tangential movement of the imaginary rack from which it is generated. Cutting this wormwheel oversize or feeding the hob in deeper will not change the pitch diameter, but it will change the form of tooth. This same rule applies to spur and helical gears.

Fig. 15 illustrates the method of thread-milling a worm. The job shown might be a triple-threaded worm or a triple-threaded lead-screw with an Acme thread. The calculations involved are practically the same as those required to figure out gears on a lathe. The cutter is traveled along the axis of the work a distance of one lead for each rotation of the work. The difference is that in this case a milling cutter is used instead of a lathe tool. The axis of the milling cutter is inclined so that it falls at right angles to the thread that is being cut, and the work rotation is at a suitable peripheral speed for a milling feed. In addition to the substitution of a milling cutter and the corresponding change in the speed of work rotation, one theoretical point must be considered. A lathe tool with its cutting profile in a plane passing through the axis of the work will reproduce itself in the thread. In other words, if the lathe tool is ground to an angle of 29 deg. and it is set straight, it will produce a thread with a 14½-deg. pressure-angle on each side. The teeth of the thread-milling cutter are, however, operating in a plane normal to the threads; so, there is a difference between the axial pressure-angle of the thread and the angle of the cutter or normal pressure-angle of the thread. In cutting worms of steep angles such as are used in motor-truck axles, the difference between the normal and the axial pressure-angles becomes clear and it is necessary to make the required correction in angle of the cutter, for worms are commonly specified by the axial pressure-angle. We usually know what linear or axial pressure-angle is desired and it is necessary to specify a cutter to produce it. We have evolved a formula for making this correction; reduced to its simplest form, it is as follows:

> **The tangent of the Axial Pressure-Angle times the cosine of the Thread-Angle equals the tangent of the Normal Pressure-Angle**

I will not attempt to explain how this formula is derived, for it is a long process. It is possible to reduce most of the calculations on worms and helical gears to a simple form which requires the solution of only one triangle. In this connection I will present my method of teaching the shop man in one lesson enough of the science of trigonometry so that he will be equipped to make worm and helical gear calculations.

Helical and Worm-Gear Calculations

Fig. 16 shows at the left a plain right-angle triangle. Taking the base-line as a radius and striking an arc, it is an easy matter to identify the side of the triangle which is naturally called the tangent. The base-line we will call 1.000. I merely tell the student that the base-line is 1.000 and that the tangent for any given angle is found in the book. If he remembers this and has mathematical ability enough to multiply and divide, he will appreciate the fact that with a base-line of 2 he can find the perpendicular or tangent side of the triangle by multiplying the tangent he finds in the book by 2. He also should appreciate the obvious fact that quantities multiplied together can be divided again; so, in case he happens to know the perpendicular side of the triangle and does not know the length of the base-line, he can divide the perpendicular by the tangent of the angle and find the base-line. It equally is obvious that, knowing both the perpendicular and the base-line, it is possible to find the tangent by dividing the perpendicular by the base-line and, having found the tangent, he can look in the book and find out what the angle is. The next step in this lesson is to turn the triangle over and look at it from the other side, as in the middle view, calling the student's attention to the fact that it can be turned up-side down or sidewise to fit his problem.

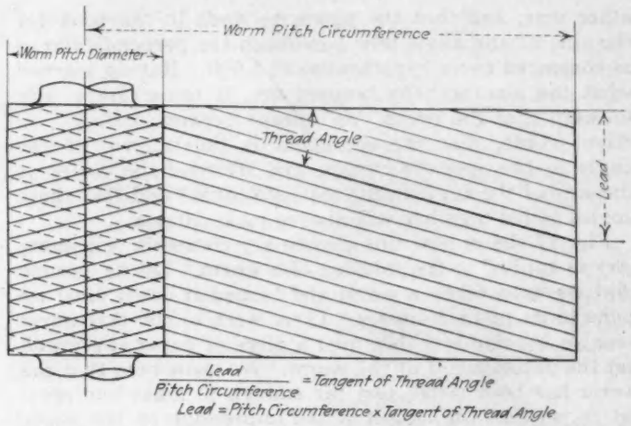
Worm Pitch Circumference
Worm Pitch Diameter
Thread Angle
Lead
Lead / Pitch Circumference = Tangent of Thread Angle
Lead = Pitch Circumference x Tangent of Thread Angle

Fig. 17—An Application of the Right-Angle Triangles Shown in Fig. 16 to the Solution of a Worm

Another right-angle triangle is shown at the right of Fig. 16 to illustrate the sine. To impress this on the student's mind I point out that the hypothenuse is called 1.000 in this case and that the sine and the tangent approach the same value when the angle is very small. If the angle were only 1 deg., it would not make much difference whether he used the base-line or the hypothenuse as a stick to measure the perpendicular. It is easy to remember what the word "tangent" means and then all he has to do is to remember that the sine is measured the

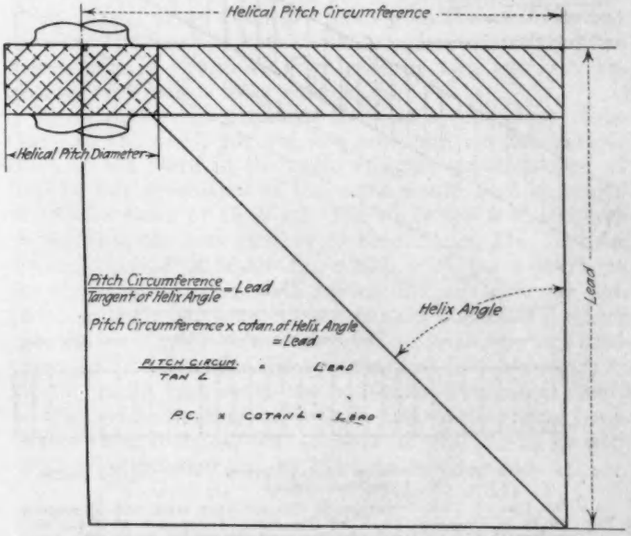
Helical Pitch Circumference
Helical Pitch Diameter
Pitch Circumference / Tangent of Helix Angle = Lead
Pitch Circumference x cotan. of Helix Angle = Lead
Helix Angle
Lead
PITCH CIRCUM. / TAN ∠ = LEAD
P.C. x COTAN ∠ = LEAD

Fig. 18—Corresponding Diagram for a Helical Gear

other way, and that the figure he finds in the book for the sine of any angle tells how much the perpendicular is as compared to an hypothenuse of 1.000. Having learned what the sine and the tangent are, it is necessary only to learn that the prefix "co" means "corresponding"; in other words, that the cotangent is the tangent of the angle in the opposite corner, and likewise the cosine is the sine of the angle in the opposite corner and that these angles added together will always make 90 deg.

Fig. 17 shows how this elementary course in trigonometry is applied to the solution of a worm. Let us assume that we have taken a worm and turned it down until we come to its pitch diameter. If we were to roll this worm over an ink-pad and then over a piece of paper, we would get the development of the worm. We show here that the worm has been rolled just far enough to make one revolution, so that the length of the impression on the paper is the pitch circumference of the worm. Each tooth makes a straight line and the angle between this tooth and the top edge of Fig. 17 is the thread angle of the worm. We know the pitch circumference of the worm and we know the lead of the worm; so, we are able to construct a right-angle triangle with two known sides. Taking the triangle in the center of Fig. 16 and turning it upside down, we find that it fits into our diagram; so, we know that dividing the lead by the pitch circumference will give us the tangent of the thread angle, or, if we happen to know the pitch circumference and angle, we could find the lead by multiplying the pitch circumference by the tangent of the angle.

Fig. 18 is a very similar diagram made with a helical gear. So far as the calculation of lead, diameter, angle and the like is concerned, a helical gear is the same thing as a worm except that we make a practice of speaking of the "tooth angle" or "helix angle" in a helical gear, meaning the angle between the tooth and the axis of the gear; whereas, we speak of the "thread angle" in a worm, meaning the angle between the thread and a line perpendicular to the axis. Having rolled the gear out on a flat surface, in the same manner that we did the worm, and

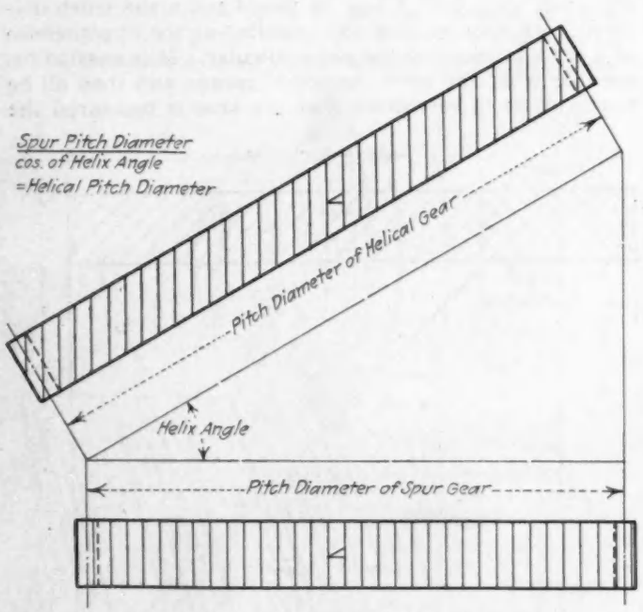

FIG. 19—THE MOST COMMON CALCULATION IN WORKING WITH HELICAL GEARS

By the Use of This Diagram in Conjunction with the Triangles of Fig. 16 It Is Possible To Find the Pitch Diameter of a Helical Gear Knowing the Helix Angle, or To Find the Helix Angle Knowing What the Diameter of the Gear Should Be.

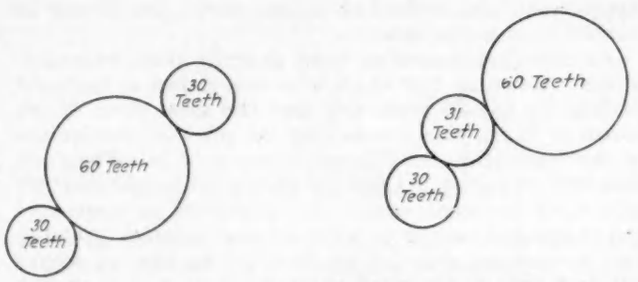

FIG. 20—DIAGRAM SHOWING HOW IT IS POSSIBLE TO MAINTAIN THE SAME RATIO IN A GEAR TRAIN BY CHANGING THE HELIX ANGLE TO MAKE UP FOR A VARIATION IN THE NUMBER OF TEETH

	Cosine of Angle, Deg.	Min.		Cosine of Angle, Deg.	Min.
29/30 = 0.96667	14	50	7/8 = 0.8750	28	57
28/30 = 0.93333	21	2	8/9 = 0.8889	27	16
27/30 = 0.90000	25	50	8/10 = 0.8000	36	52
26/30 = 0.86666	29	56	9/10 = 0.9000	25	51
25/30 = 0.83333	33	33	10/12 = 0.8333	33	33

forming a right-angle triangle, we find that we know the pitch circumference and the helix angle and we want to find the lead. The triangle at the left of Fig. 16, tilted up on its left side so that the tangent becomes pitch circumference and 1.000 becomes lead, serves the purpose this time, and it is shown that the pitch circumference divided by the tangent of the angle equals the lead. Should we happen to know the lead and not the angle, we can find the tangent of the angle by dividing the lead into the pitch circumference.

Fig. 19 shows what is probably the most common calculation in working with helical gears; that is, to find the pitch diameter of a helical gear knowing the helix angle, or to find the helix angle, knowing what diameter the gear must be. We have here a right-angle triangle of which the base-line is the pitch diameter of a spur gear and the hypothenuse is the pitch diameter of a helical gear with the same number of teeth and the same pitch. If the teeth of one gear are traced across the diagram, it will be found that they coincide with the teeth of the other gear. If a small triangle is drawn in between two teeth of either gear, a triangle exactly similar to the larger triangle will be formed.

Let us take the triangle shown at the right of Fig. 16, just as it stands, and lay it on this triangle. We are not interested in the side that is marked "sine," but we are interested in the base-line, which is the sine of the angle in the opposite corner. It is therefore the cosine of the helix angle; and we know that the diameter of the spur gear is to the diameter of the helical gear as the cosine is to 1.000. In other words, to convert the pitch diameter of a spur gear into the pitch diameter of an equivalent helical gear, we merely divide the pitch diameter by the cosine of the helix angle.

Fig. 20 shows this formula applied to a problem which many automobile engineers had to solve a few years ago when the change was made from spur to helical timing-gears. Since the problem of arriving at a suitable number of teeth, pitch and tooth angle, is handled practically the same way today, we may find this old problem interesting. At the left is a layout of three gears with 30, 60 and 30 teeth respectively. Should we change this to 29, 58 and 29 teeth we would keep our ratios and reduce the pitch diameter of each gear by the ratio of 30 to 29, but if we give the teeth of each gear a certain amount of helix angle we can make up the difference. Therefore, we divide the smaller quantity, 29, by the larger quantity, 30, and find that the cosine of the required angle is 0.96667 or an angle of about 14 deg. 50 min. In the same manner we can reduce the number of teeth to 28

and 56, going as far as we like, one tooth at a time on the 30-tooth gear and two teeth at a time on the 60-tooth gear, obtaining the helix angles shown at the left of Fig. 20. At the right side of Fig. 20 we find another gear layout which involves a 31-tooth gear; unhappily, this is a prime number and prevents our making a change in the numbers of teeth but, as an alternative, we can change the pitch. Assuming that these are 7-pitch gears, we might keep the same number of teeth in each gear and change them to 8-pitch gears. This would reduce the pitch diameter of each gear by the ratio of 8 to 7. Following the same process of dividing the smaller quantity by the larger quantity, we find that a change from a 7 to an 8-pitch gear gives us a cosine of 0.8750 or an angle of 28 deg. 57 min. If we started with 8-pitch and changed to 9-pitch gears, we would get a cosine of 0.8889 or an angle of 27 deg. 16 min.; likewise a change from 9 to 10-pitch gears would give us a cosine of 0.9000 or an angle of 25 deg. 51 min.

Some of the helix angles shown are still in use on popular cars. It is only natural that, having once established these odd angles to accomplish the desired change to helical gears without disturbing gear-centers and discarding a lot of blanks, these angles were adhered to in many cases and have even been copied on new designs.

Hobbing Helical and Worm Gears

Fig. 21 shows the process of hobbing a right-hand helical gear. Note that the direction of the cut on this gear is not along the axis of the gear, but at a considerable angle to the axis. This emphasizes the importance of supporting the work arbor rigidly at both ends instead of at one end only. It will be observed that the designer has paid considerable attention to rigidity in the construction of this machine. Fig. 22 is a diagram of the problem of setting up a gear-hobbing machine to generate a given helix angle. The first step in making this calculation is to determine the lead of the gear as explained in connection with Fig. 18. Let us assume the lead in this case to be 10 in., the feed per revolution of the blanks to be 0.050 in. and the number of teeth to be 50, using a right-hand single-thread hob to cut a right-hand helix. Having 50 teeth in the gear and 1 thread in the hob, we must gear up so that the hob makes 50 revolutions for 1 revolution of the blank. Each hobbing machine has a particular constant between the hob and the work spindles. In this case the constant is 32 or, in other words, when the change-gear train has a ratio of 1 to 1, the machine will be set up to cut 32 teeth. To

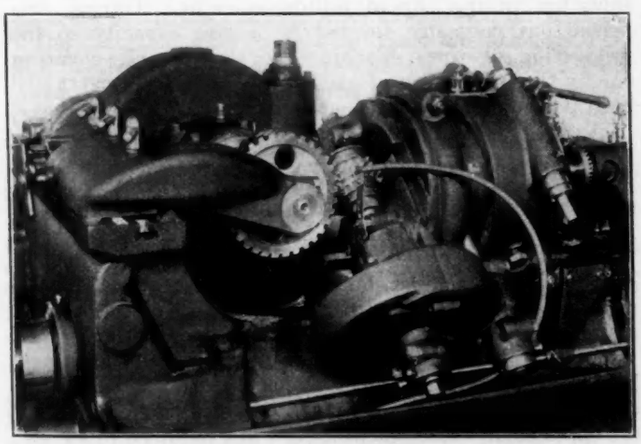

Fig. 21—Hobbing a Right-Hand Helical Gear

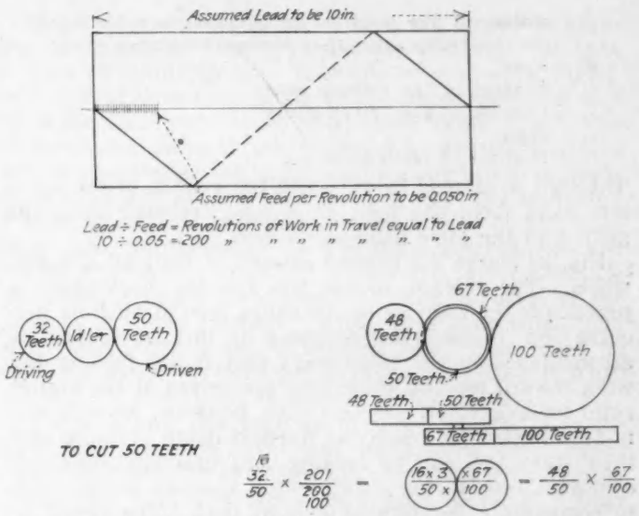
Assumed Lead to be 10 in.
Assumed Feed per Revolution to be 0.050 in
Lead ÷ Feed = Revolutions of Work in Travel equal to Lead
10 ÷ 0.05 = 200 " " " " " " " "
32 Teeth
Idler
50 Teeth
Driving
Driven
67 Teeth
48 Teeth
100 Teeth
50 Teeth
48 Teeth
50 Teeth
67 Teeth
100 Teeth
TO CUT 50 TEETH
10/32 × 201/200 = (16×3)/50 × 67/100 = 48/50 × 67/100

Fig. 22—Diagram Showing How a Gear-Hobbing Machine Should Be Set Up To Generate a Given Helix Angle

cut 50 teeth, we must therefore use a 32-tooth gear driving a 50-tooth gear, or some other combination producing the same ratio.

Having selected a feed of 0.050 in. per revolution of the blank, we find that in cutting a gear face of 10 in. the gear blanks will have made 200 revolutions. We arrive at this by dividing the lead of 10 in. by the feed of 0.050 in. This is the result we would have if they were spur gears, but it happens that we want to cut helical gears and we must therefore introduce an extra revolution. This extra revolution amounts to the same thing as setting up a universal milling-machine so that the work rotates one turn while the cutter travels the length of the lead desired. The machine is making 200 revolutions normally but to generate this helix we must make 201 revolutions; therefore, we multiply the gear ratio by the quantity 201/200. This gives us the combination:

$$(32/50) \times (201/200)$$

which equals

$$(16 \times 3 \times 7) \div (50 \times 100)$$

Reducing this to workable gear-sizes we have:

$$(48/50) \times (67/100)$$

The diagram in Fig. 22 shows how this gear combination would be put together, using a compound in place of the idler. If we find after setting up the machine that we want the work to rotate in the opposite direction, we merely put in one more idler gear or take one out, according to which is more convenient.

In obtaining exact results there is a correction to be made in the feed, for we are now making 201 revolutions of the work in the cycle and our assumed feed of 0.05 in. per revolution of the work would give us a lead of 10.05 instead of 10.00 in. The corrected feed is found by dividing the new number of revolutions, 201, into the desired lead of 10.00000 in., which gives us 0.04975 in. To allow for making such corrections as this, our machine is designed with a change-gear mechanism which permits an almost infinite number of feed-gear combinations. Without such a feed mechanism it is necessary to let the error pass or to use a special change-gear with a large prime number of teeth in the rotation gear train. Stated as a formula, the problem of gearing-up to generate a helical gear on any hobbing machine is:

$$G/G_1 = (C \times L/F) \div (N[(L/F) \pm 1])$$

where

C = Number of revolutions made by the hob for 1 rev-

olution of the work when change-gears having a ratio of unity are put in the work rotation train

F = Feed
G = Product of the driving gears
g = Product of the driven gears
L = Lead
N = Number of teeth to be cut

The sign $\pm$ is read "plus" when the gear is of the *opposite* hand from the hob; it is read "minus" when the gear is of the *same* hand as the hob.

Fig. 23 shows the modern process of hobbing a wormwheel. The relation of the hob and the wormwheel is practically the same as on the oldest type of hobbing machine and, in fact, the roughing of this wormwheel is accomplished in the same way; that is, by feeding the work toward the hob while both are driven at the proper ratio to each other. In this case, however, we stop the in-feed before we reach the finished depth of tooth and then start the hob to feeding longitudinally upon its own axis, introducing a differential rotation of the work to compensate for this tangential feed. The result is that each tooth of the hob is moved along its axis to a great number of successive positions, accomplishing the effect of a hob with an infinite number of teeth. This is the latest method of producing worm gears such as are used in truck axles. The importance of this longitudinal feed is increased by an increase in the thread-angle of the worm for, the steeper the thread-angle of the hob is, the fewer teeth there are in any one thread. This is a comparatively new machine which we have developed for this particular class of work, to allow the designer to employ the steeper thread-angles which are more efficient and accommodate themselves more readily to the gear-ratios desired.

Ring-Type Thread-Milling

Fig. 24 shows an operation which is sometimes called hobbing, but we prefer to call it ring-type thread-milling; together with the machine upon which it is done. Th ring-type cutter is not strictly a hob because it has no lead and is merely a gang of single cutters made in

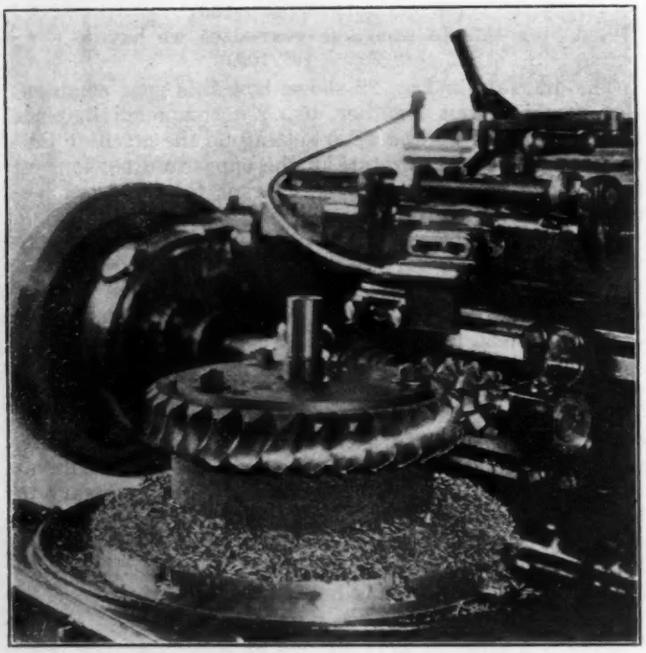

Fig. 23—Hobbing a Wormwheel

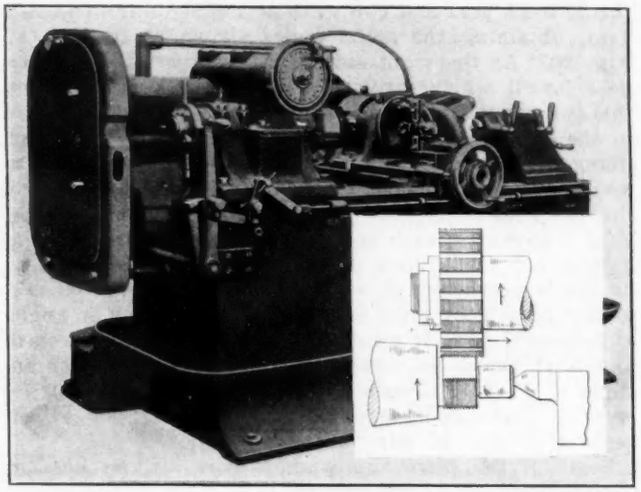

Fig. 24—Milling an Ordinary V-Thread on a Shaft by the Use of a Ring-Type Cutter

one piece. The operation shown is milling an ordinary V-thread on an axle shaft, transmission shaft, steering-knuckle or some such part. The axis of the cutter is set parallel to the axis of the work and is rotated at a suitable milling speed independent of the rotation of the work. The cutter is, however, given a longitudinal movement upon its own axis, parallel to that of the work, at a rate equal to one lead of the thread while the work makes one revolution. With the cutter in motion, the first operation is to engage the feed, which starts the work rotating and the cutter traveling parallel to the axis of the work. The operator then brings the cutter in to its full depth, cutting a complete thread across the full face of the part to be threaded. After the work has made slightly more than one complete rotation to insure that the thread is finished all the way around, the cutter is backed out and we have a complete thread. This method of cutting complete threads at one rotation of the work is similar to the so-called "hobbing" of tap and die chasers. It produces a very accurate thread and the beauty of it is that all of the threads are alike.

This process of producing threads has gained much in popularity as a result of the war. Many manufacturers who contracted to deliver large numbers of shells and then found that the Government specifications for thread limits could not be met by ordinary methods, owe their salvation to the thread milling-machine. During this period our company devoted its entire capacity to the production of these machines for war work, covering chiefly the production of shells, aircraft-engine parts and even plug and ring thread-gages.

THE DISCUSSION

W. C. Keys:—Is the Lees-Bradner gear-hobbing machine readily suitable for hobbing and milling threads, and can it mill internal threads?

Glenn Muffly:—We sometimes mill threads on our gear-hobbing machines, but our gear-hobbing and thread-milling machines are distinct types. It is possible to mill an internal thread by the method shown in Fig. 24, although for internal work we build collet-type machines, holding the work in collet chucks, either air or hand operated, or in a special fixture of some sort. The cutter spindles on these machines are not required to swivel, because internal threads are cut only with ring-type cutters.

M. R. WELLS:—What is your method of determining the shape of the milling cutter?

MR. MUFFLY:—The ring-type thread-milling cutter has a tooth-angle practically the same as the thread to be produced. The thread has a lead, but the cutter has no lead; so, naturally there is a slight difference in the pressure-angle of the thread, although this is so small as to be negligible. The pitch of the thread is taken along the axis of the work and, since the cutter is parallel to the axis of the work, the distance from tooth to tooth of the cutter is the same as the pitch of the thread. If we were to tilt the axis of the cutter we would have two errors; one error in the lead of the thread and one error due to the fact that only one point on the cutter would cut a full-depth thread. It would be necessary to design a special form of cutter to cut a correct thread with a multiple cutter on a tilted axis.

A. M. DEAN:—Is the Maag gear essentially a gear of greater pressure-angle?

MR. MUFFLY:—Yes; it gives a tooth with a wide base and wholly different contour. A similar curve is shown on the involute layout in Fig. 5. Any part of the involute curve desired can be selected and a pair of gears designed to use it. If a gear blank of suitable diameter for 30 teeth were cut on a hobbing machine as a 28-tooth gear, something different from the ordinary involute curve would result. The Maag system employs a rack to generate the gear tooth and is essentially the same as hobbings, so far as tooth generation or tooth contour is concerned, although it happens that very large pressure-angles are advocated; in other words, a different part of the involute curve is used.

E. W. WEAVER:—What is the best way to produce gears commercially?

MR. MUFFLY:—That depends upon the gear which is to be produced. I am an advocate of the hobbing method and I am pleased to say that I do not meet with the opposition now that I did in former years. Summing up the experience of automobile and engine builders rather than giving my own views, which may be prejudiced, I can say that helical timing-gears are produced almost exclusively by the hobbing process. This indicates that the majority of manufacturers have found that the hobbing method produces more smoothly running gears. Quietness is of greater importance than cost, when it comes to making the front end of an automobile engine.

In transmission gears we find more difference of opinion, although it is conceded generally that the hobbing method is the most rapid. We find a number of manufacturers using the shaping machine method on account of the fact that they have step gears and the smaller gear of the step cannot be reached with a hob. This method covers the step-gear and the internal-gear fields, while the hobbing machine fills the helical-gear field covering automobile timing, turbine-reduction and cream-separator gears, and all such applications where smooth action and high speed are of first importance. Worm gears are exclusively a hobbing proposition. The only class of gear work that has not been put definitely into one category or the other is the automobile transmission. This is no doubt due to the use of the step gear and the tendency to standardize on one type of equipment. If it is necessary to use the shaping machine method on one of the gears, the tendency is to use it on the entire gear-set. On the other hand, it is generally conceded that the hobbing method gives a greater production, and the advantages of this method tend toward the elimination of the step gear to standardize on hobbing. In the meantime we have many plants divided between the two.

The matter of tooth accuracy does not enter the problem of transmission-gear production to the extent that it does on timing-gears. It would of course be highly desirable to have quiet gears in the transmission as well as in the front end, but of what value would it be to cut transmission gears as accurately as we must cut helical timing-gears when the transmission gears are to be hardened after they are cut, thus spoiling all of the accuracy? I have often been impressed by the ridiculous situation of a manufacturer who listens to the arguments pro and con of the various gear-cutter men and, after selecting the machine which he believes will split the error of the gear tooth to the smallest fraction of a thousandth, cuts his transmission gears with great care; then, when he hardens them, they twist out of shape from 0.008 to 0.010 in., making a noisy job in spite of all his trouble.

There is only one solution to this problem. For the past few years we have been doing some development work along the line of generating gear teeth with a grinding wheel after the gears have been hardened. Gear teeth have been ground with formed wheels after hardening, to a limited extent; but this method has many limitations and it is obvious that the real solution is to generate the tooth curve after the gear has been hardened. We have obtained some remarkably smooth-running gears by this method. Some of these gears are in use in high-grade enclosed-body jobs and the passenger cannot tell whether the car is running on direct drive or through the gears, unless he has an opportunity of comparing engine speed with car speed. This new machine is not yet on the market, but its introduction may lead to changes in car design. With gears of this sort the public will not be so inclined to use the direct drive all the time. The designers will be able then to offer something new in fuel economy.

JOHN MCGEORGE:—Some years ago I read an article explaining how the tooth-form should be taken in regard to helical gears. At that time I had some large gears to make. They had a 42-in. face, a 7½ pitch and were required to run as accurately as possible. They were laid out normal to the axis and not normal to the angle of the tooth. It seems to me that Trautschild was wrong in giving the form of the tooth as normal to the angle of the tooth, because the action is at right angles to the shaft. We formerly made step gears which consisted simply of several sections side by side. That was approximately the helical-gear idea. If a wheel composed of a number of thin laminated parts were cut through with a cutter and those laminations were slipped slightly until the proper angle was obtained, the helical tooth would result but, it would be cut with the tooth profile at right angles to the shaft. Why is the tooth profile made at right angles to the tooth? Is this done to suit the present cutters?

MR. MUFFLY:—First, it is only logical to use the same cutters unless there is some very good reason for making special cutters. Second, if we should begin to lay out the curves at right angles to the axis, we would need to lay out a different curve and produce a different cutter for every helix angle employed. By the present method we use one hob to cut the entire series from a spur gear to a helical gear of 80-deg. angle. Take, for instance, a four-tooth helical pinion of about 72-deg. helix angle; it has only four teeth, yet an end-view of it or a view in line with one of the teeth shows a practical form of tooth. If we laid out a four-tooth pinion of any ordinary pressure-angle, it would not be a practical form of tooth. The difference between pressure-angle at right angles to the axis and pressure-angle normal to the tooth can be cal-

culated by a method somewhat similar to the one shown for calculating the pressure-angles of worms. If we did lay the tooth out in a plane at right angles to the axis, we would need to make the correction in pressure-angle to get a practical tooth. It should be remembered also that some helical gears run on shafts at right angles or at some odd angle to each other, but we pass an imaginary rack profile between any pair of helical gears and the direction in which this rack profile moves indicates the plane on which the tooth is really acting. This plane is normal to the tooth; it simplifies matters greatly to lay out the tooth curve in this plane or to generate from a rack in this plane.

MR. MCGEORGE: — Regarding the shaping-machine method, if you referred to the Fellows gear-shaper, will you describe the cutting of helical gears on it?

MR. MUFFLY:—The Fellows machine produces helical gears by using a special cutter for each angle of tooth to be cut. The cutter in this case resembles a helical gear instead of a spur gear, as is usual on the Fellows machine. While the cutter travels up and down it must also be given an oscillating rotation about its own axis, so that the teeth of the cutter will pass through the teeth of the gear at the proper angle. This introduces a complication in the grinding of the cutter and calls for a master cam on the machine that conforms to the helix angle. The method is used only on helical gears of comparatively small angle.

MR. DEAN:—Will you describe the hobbing of spiral bevels?

MR. MUFFLY:—That process is possible, but it is not commercially practicable at present. To explain what is necessary, we must first consider a straight bevel gear which has been hobbed experimentally with a tapered hob. The hob is tapered, not merely in the ordinary sense but with an actual change of pitch, because a bevel gear changes in pitch when traveled across its face. Starting with the smaller end of the hob working on the smaller diameter of the gear, we would feed the hob along the pitch cone of the gear, introducing at the same time a longitudinal feed of the hob to bring teeth of heavier pitch into play. This longitudinal feed of the hob would require a differential rotation of the work similar to that used in hobbing a wormwheel with the longitudinal feed of hob. In addition, we must consider that the tapered hob is increasing in diameter as it feeds longitudinally; so, we must make a correction in the angle of hob travel along the pitch cone of the gear, increasing this angle to a point which will allow the pitch cone of the hob to follow that of the gear. To hob a spiral bevel gear we would need to introduce a differential action to produce the spiral, in addition to all of these factors. It does not appear that this process is likely to be developed commercially for some time to come.

MR. MCGEORGE: — Does hobbing produce a constant curve on the teeth?

MR. MUFFLY:—In any method of gear generation with a milling or planing tool, the tooth is produced by a succession of cuts which blend together to form the involute curve. In hobbing that curve is produced by a succession of lines which curve slightly in the same direction as the tooth. These are spoken of ordinarily as straight lines, because the side of the hob tooth is straight, but there is a generating action while the hob tooth is at the finishing point, and this action curves the cut slightly to conform to the involute curvature. In shaping a gear the tooth of the cutter has a curvature away from the curvature of the gear tooth it is generating, but with a slow enough feed, that is, rotating the blank and the cutter through small enough angles between cuts, this is not noticeable on the finished product.

MR. MCGEORGE:—Will it give a continuous curve?

MR. MUFFLY:—Either system generates a continuous curve so far as practical purposes are concerned. A few years ago there was considerable argument pro and con regarding the so-called flats on hobbed gears. A number of writers attempted to prove that there was something wrong with the principle of tooth generation from the rack profile. The facts are that these flats existed only in the imagination; what they saw were the irregularities resulting from a lack of experience with the hobbing process. The most common of these errors were the setting of the hob off-center, improper grinding of the hob, using a standard involute hob of small pressure-angle on a pinion with too few teeth for the unmodified involute curve, and using hobs that had been badly distorted in hardening. Except for the tooth distortion in hardening, all of these errors can be eliminated by any operator who will follow instructions carefully. The tooth distortion in the hob was overcome by the process of grinding hob teeth on the sides, after hardening. This process has been in vogue for a number of years, and there is no longer any excuse for producing incorrect gears. If we were to lay out a tooth curve by the old-fashioned method for use on a 20-tooth pinion, we would not make it a true involute curve. The true involute curve on an ordinary pressure-angle makes an undercut tooth when the number of teeth in the pinion is too small. It is therefore customary to modify the tooth-form on pinions of few teeth. The introduction of hobbing does not change the basic principle of the involute curve, so we still find it necessary to modify the tooth-form on pinions. One reason for the introduction of the 20-deg. pressure angle is that this under-cutting on the pinion does not develop so soon as it does with the 14½-deg. pressure angle. This is, however, a question of tooth-form desired, not a question of process to be used in cutting the tooth.

R. A. TOWNSEND:—How is the master form made?

MR. MUFFLY:—In making a standard involute hob, the master form is merely a lathe tool with straight sides at an included angle of 29 or 40 deg. according to whether we are making a 14½ or a 20-deg. pressure-angle hob. The master form for the old-style gear-cutter is made by establishing first the pitch-circle, then finding the base-circle and then laying out the curve as has been shown. This curve is then used as a pattern for the forming tool which is used to make the cutter that cuts the gear. There really is no master form used in connection with generated gears, except in the case of special tooth-forms such as sprocket wheels, splined shafts, ratchet-wheels and the like. On a hobbing machine the master form can be said to be the hob itself, with its straight-sided rack-teeth which generate the gear teeth directly. On the gear shaper, the master form is the same straight-sided rack-tooth, represented by the flat surface of a grinding wheel which is used to generate the cutter in the form of a gear, and this gear-shaped cutter is used to cut other gears. The gear-shaper generating process requires two steps; first, from the rack profile of the grinding wheel to the cutter; second, from the cutter to the gear. The resulting gear tooth is practically the same as the tooth generated by a hob in one step.

Fig. 12 shows a hob made up entirely of teeth each one of which is a master form for the standard involute curve on any spur or helical gears of this one pitch. These hob teeth are ground on the sides with a flat wheel. All of the cutting edges are straight lines. The method

of manufacture is first to rough out the high-speed-steel racks which are to be the inserted blades of the hob; second, placing these blades in a holder similar to the hob, but with gashes parallel to the axis and the teeth in rings instead of in thread form, we grind the sides of the teeth. This is a plain grinding operation. We merely grind rings with the required angle on each side. After the hob blades have been ground in this way, they are removed from the grinding fixture and placed in the hob body. Each blade was tilted forward during the grinding operation. When placed in the hob it is tilted back to its normal position with the cutting face radial. The gashes in the hob body are at an angle normal to the lead of the hob. When assembled in the hob, the blades are adjusted longitudinally until they check exactly for the lead on each successive tooth, in a special machine we have built for this purpose. The ends of the hob blades are then ground and the whole locked together permanently. Cutting a gear with such a hob represents the most direct form of gear generating from the involute rack, except possibly the grinding generating method mentioned earlier in connection with transmission gears.

H. G. WELFARE:—How long can a hob be used?

MR. MUFFLY:—That depends upon so many factors that I can give only comparisons. Some shops believe in grinding a hob every 2 hr. and some once a week. There is a wide variation in the speeds used in different shops. The tool cost for hobs is less than that for other types of generating machines used on spur and helical gears. This is especially true in the case of helical gears. There is not so much difference between the cost of old-style single-cutters and of hobs. I am speaking in terms of the cutter cost per 1000 gears. It has been noticed that the metal removed by one tooth of a hob during its life is greater than the metal removed by one tooth of an old-style single-cutter during its life. We also find hobs being run successfully at cutting speeds that are not considered practicable in ordinary milling practice.

It is not our custom to recommend such excessive speeds, but they are being used. As a general thing we think of a certain number of cutting feet per minute as the limit of a certain steel in a certain material, but there really is no reason why a milling cutter and a lathe tool should stand exactly the same cutting speed. On the one hand, a tooth of the milling cutter takes out its chip and makes the greater part of a revolution before it removes another chip, allowing an opportunity for coolant to flow over the tooth. On the other hand, the lathe tool, although buried continuously in the cut, is moving forward into cool metal. Hobbing is essentially a milling operation, but the hob teeth do not operate continuously in one groove as the teeth of a milling cutter do. The hob tooth has an opportunity to cool during the greater part of its revolution and, to some extent, it has also the advantage enjoyed by the lathe tool; that is, it is constantly cutting into new metal instead of going back to the point at which it took out the last chip. This distribution of heat all around the blanks is not only an advantage from the standpoint of hob life, but it eliminates one troublesome source of gear distortion encountered in other methods of gear cutting.

H. N. ANDERSON:—What is the theoretical error in cutting a spur gear with a Fellows machine?

MR. MUFFLY:—I think that the error you have in mind is not so much an error in cutting a gear as it is the error produced in grinding the cutter to sharpen it. So far as the gear-tooth generation goes, the Fellows method does the same thing that the hobbing method does, save for a slight modification made necessary by the fact that a perfect rack will generate a perfect involute curve but a perfect involute curve will not in turn afford a complete generation of the involute rack. This is taken care of in the design of the cutter, which is slightly modified from the standard involute. The gear-shaping machine representative and the exponent of gear hobbing usually argue somewhat as follows:

The latter points out that the cutter of the gear shaping machine is made with a clearance and is therefore smaller in diameter at the back than at the cutting face. Since the cutter is sharpened by grinding off the cutting face, it is gradually decreased in diameter. The gear-hobbing machine man usually makes the mistake of claiming that this reduces the pitch diameter of the cutter. This gives the gear-shaping machine advocate a chance to state that the pitch diameter of his cutter is constant, and that it is possible to cut a tooth that is all addendum or one that is all dedendum. This usually leaves the innocent bystander with about as much information as he had before. He does not know which one to believe. As a matter of fact, the cutter of the gear-shaping machine is reduced in outside diameter and in bottom diameter by grinding. It is admittedly a tooth of a different form after it has been ground, for the addendum is shorter and the dedendum is longer than before. Theoretically, this cutter tooth will generate the same gear tooth that it did before grinding, but it is shorter and will not reach in far enough to cut the tooth to the same depth that it did before. If we set the cutter in to the same depth that it cut before grinding, we upset the theory and make the pitch-circle of the cutter overlap the pitch-circle of the gear instead of merely touching it.

We sometimes hear the argument advanced that a hob also is reduced in diameter by sharpening. This is true, but reducing the diameter of a hob does not affect the form of the tooth. The tooth is cut with a forming tool or ground on the sides in a backing-off machine. The relief on the top of the tooth also applies to the space at the bottom between the teeth and to the surface on the sides of the tooth. The hob tooth has the same amount of addendum and dedendum, when ground back to the breaking point, that it had when new. A hob of a certain pitch might be ordered in any diameter that the hobbing machine will swing. The larger the diameter is, the smaller the helix angle will be. Grinding a hob to sharpen it merely reduces the diameter and increases the helix angle by a few seconds. If it is desired to be absolutely right theoretically, a slight correction would be made in the angular setting of the hob spindle after grinding the hob. In actual practice it is impossible to detect this difference in hob setting on the finished gear.

MR. WELFARE:—Does not the grinding of the hob affect the lead also?

MR. MUFFLY:—Sharpening the hob does not change the lead. It changes only the diameter and the thread-angle. Lead is a function of hob length and, since we have not reduced the length of the hob, we have the same distance from center to center of two adjacent teeth.

MR. WEAVER:—How are the gears cut that must withstand the highest duty? What process was used in cutting the gears that were used in airplane engines? I refer to the gears for propeller speed reduction.

MR. MUFFLY:—The gears used in airplane engines are mainly timing and oil-pump gears. During the war I was building airplane engines and used the hobbing method to produce all gears except one which could not

(*Concluded on page* 242)

The Design of Motor Trucks for High-Speed Service

By Charles O. Guernsey[1]

Indiana Section Paper

SUGGESTED services suited to fast trucks up to 2-ton capacity, where speed, versatility and convenience are highly desirable, are tabulated and commented upon. The evolution of the speed-truck as the result of a compromise between the delivery-wagon and the solid-tired heavy-duty truck is discussed.

Seven specific requirements for a high-speed truck are stated, a summary being given in eight divisions of the advantages obtainable through use of a truck of this type. Stating that the gear-ratio should be such that road speed will hold the engine speed within safe limits without a governor, the author outlines the type of engine needed, its design requirements and performance ability, following this with a consideration of maintenance and operating costs with regard to the possibilities of keeping them low. After a further discussion of truck equipment and gear-ratios, the author refers to his previous paper, Cushioning in Motor-Truck Design.

A summary of data contained in Department of Agriculture Bulletin No. 910, resulting from a comprehensive questionnaire widely circulated among farmers to ascertain their truck practice and preferences, is presented in the discussion following the paper.

THERE is a consistent and growing demand for faster motor trucks. The success of many motor-truck applications to various services is dependent upon the ability to cover certain distances within a definite time. Users realize that a small truck carrying, say, 1½ tons at an average of 18 to 20 m.p.h. can do as much work as a 3-ton truck that averages one-half of that speed. Then there are conditions when speed is essential because of the nature of the load. Vegetables must be delivered promptly and milk must reach the creamery before it sours. Many commodities require prompt delivery. Fast trucks up to 2-ton capacity will fit admirably into numerous lines of business, as it is indicated below. In practically all these fields, speed, versatility and convenience are very desirable and this creates a demand for high-speed trucks.

SERVICES SUITABLE FOR FAST TRUCKS UP TO 2-TON CAPACITY

(1) Marketing of general farm products, dairy products, vegetables, fruit, green stuff, live stock, grains, etc.
(2) Delivery service of department stores, furniture houses, hardware stores, laundries, florists, dyers and cleaners, butchers, bakers, bottlers, newspapers, commission merchants, wholesale grocers, etc.
(3) General hauling in express service, inter-city express, furniture moving and baggage transfer
(4) Public utilities as trouble and pickup wagons for power, water, light, gas and telephone companies
(5) National, State and Municipal uses as mail wagons, fire apparatus, salvage corps trucks, patrols, ambulances, etc.
(6) Passenger hauling as interurban buses, city bus work, charabancs and station and hotel transfer

To indicate the possibilities in saving mileage, suppose a wholesale grocery located at the center of Indianapolis requires three large trucks to make its deliveries to the surrounding country towns. The firm would need to divide its territory among those three trucks to serve it all. That would require a great amount of back-hauling and, due to the somewhat limited speed, only a comparatively limited radius, say 20 miles, could be covered. By using lighter, faster trucks and making more deliveries the firm can operate at a greater radius and route its trucks more directly. Again, there are many cases where some person is operating from a point where deliveries are required in both directions on the same day. The quantity of merchandise for some point may be small one day and the next day great. He can in such a case send more than one truck to that particular point. The important thing is that he can meet conditions as they arise and is not restricted as to capacities, distances or directions, as rigidly as he would be with slower, larger trucks.

It was impossible to meet the requirements of this new demand fully until the recent development of cord pneumatic-tires for trucks. The sizes in which this new type will be manufactured depend on the success of the pneumatic tire for trucks. Sizes of from ¾ to 2-ton capacity are now being made and, if experiments at present under way meet with commercial success, it will be possible to build trucks of 5- or 6-ton capacity to operate at a speed of 25 m.p.h.

The speed-truck that is being evolved is the result of a compromise between the delivery wagon and the solid-tired heavy-duty truck.

Almost as early as the time when the old single-cylinder engine became obsolete for passenger-carrying purposes, enterprising garage and repair men began fitting old passenger-car chassis with some sort of box on the rear end and utilizing them commercially. The next step was the marketing of delivery cars by passenger-car builders, the body usually being mounted on the standard passenger-car chassis. In some cases minor changes were made to meet the conditions better, but these vehicles have not progressed beyond the delivery-car stage, even today. In the meantime the builders of motor trucks had attempted to meet the requirements by producing a light solid-tired vehicle. These trucks retained the characteristics of the large truck to a great extent; they were heavy, slow and somewhat noisy. However, they inherited also the good qualities such as stamina, power, durability and low maintenance cost. It will be seen that the commercial cars evolved from the passenger vehicles had certain advantages and that the light truck had other advantages. There has been no truck that combined all the desirable qualities.

Requirements of a High-Speed Truck

The development of the cord pneumatic-tire for trucks now makes it possible to combine the desirable qualities of both classes previously in the field. The speed-truck must have the speed, flexibility and easy riding qualities of the passenger car, and the power, capacity, endurance and stamina of the heavy truck. In addition, it must

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have some qualities not possessed by either of its predecessors. New problems are encountered and they must be met. We believe that, to be successful, such a truck must fulfill the requirements of

(1) A sustained speed capacity of 25 to 30 m.p.h., with a maximum speed capacity of about 40 m.p.h.
(2) Sufficient ability to climb a 5-per cent grade on high gear while carrying its rated load
(3) Sufficient gear-reduction and power to slip the driving-wheels under any ordinary condition, while carrying its rated load
(4) Low operating and maintenance costs
(5) Easy riding
(6) Light weight, to accomplish item (4)
(7) Full equipment, including electric starting and lighting apparatus, an electric horn, a speedometer or an odometer, and a power-driven tire-pump

It does not appear to be necessary to justify the design and use of a truck of this new type, but a statement of a few of its advantages to the user may make the need for high-speed trucks more evident. The speed truck must comply with the following specifications if we are to give the user the advantages to which he is entitled. Some of the advantages which result in various lines of business are due to

(1) The greater number of deliveries that can be made in a day, because of higher speed
(2) The greater radius of operation that can be secured
(3) The fact that perishable commodities can be brought to market in better condition because of the saving in time and the smoother riding
(4) The ability of a 1½-ton speed-truck, as compared with a large truck, to deliver under proper conditions as much merchandise as a heavy, slow, 3½-ton truck, because of higher speed and more direct routing
(5) The possibility of purchasing two small trucks for about the cost of one truck of twice the capacity and delivering three to four times the loads because of their superior speed and maneuverability
(6) The delivery service becoming more mobile because of the smaller size of the delivery units, thus avoiding much of the extra hauling that results from serving a large territory with one truck
(7) The practicability of operating a speed-truck at less expense and with fewer stops for repairs, as compared with the older type of delivery truck
(8) The great advertising value of the quiet operation and good appearance of these trucks

Governing the Engine and Traction

The pneumatic tire makes operation at a speed of 30 m.p.h. perfectly feasible, but trucks designed originally for solid tires cannot capitalize this advantage because the engine would be turning over at too high a rate of speed. Some trucks are being advertised as speed-trucks that do not meet the conditions. They have the same engine and gear-ratio as are required for solid tires. Engines in such trucks are forced to turn over at such a high rate of speed that trouble is sure to result. These engines generally have been designed for use with a governor, and they cannot be operated safely at speeds greatly in excess of the governed speed. If, on the other hand, the gear-ratio be changed to permit higher speed, the performance ability must be sacrificed. Therefore, the speed-truck must have either an engine that can operate at a high speed for long periods or a very high gear-ratio. It seems that a compromise will result. Engines will be operated at somewhat higher speeds and gear-ratios will be higher so that, at a speed of 30 m.p.h., the piston speed will be between 1200 and 1400 ft. per min. This will depend upon the design of the engine.

This high-speed type of truck should not have a governor. The gear-ratio should be such that road speed will hold the engine speed within safe limits. The design should follow passenger-car practice in this respect. There is a difference in that although passenger cars are capable of a speed of about 60 m.p.h., they operate normally at about 18 m.p.h., or less than one-third of the maximum speed, but the speed-truck will operate at about one-half of its maximum speed. The engine of the speed-truck will be operating more nearly on full-throttle at all times than the passenger-car engine; therefore, it must be capable of operating at high speed and under heavy loads, which is a combination that is encountered in neither the heavy truck nor the passenger car. Some engine builders have considered this class of service more severe than heavy truck work.

To meet these conditions the engine must have a good oiling system and a good cooling system. It must have a thorough circulation of water around the combustion-chamber and particularly around the valves and spark-plugs. The bearings must be large, the crankshaft stiff and the cylinder walls and pistons must be fitted within very close limits. The engine must be free from objectionable vibration at all speeds, because no governor will be provided to hold the speed below one that would cause a bad period; and, due to the high gear-ratio, it must have more power than is provided in solid-tired trucks of like capacity, to give the necessary performance.

Experience has shown that, for ordinary territory, it should be possible for a truck on high gear to climb a 5 per cent hard-surfaced grade. This ability can be changed slightly by altering the gear-ratio to meet the conditions in different territories. To meet this requirement the truck must have an ability of about 0.080 according to the formula

$$A = (T \times G \times E_t) \div (r \times W)$$

where

A = ability of the truck
E_t = efficiency of the axle and the transmission in percentage
G = gear-ratio
r = radius of the wheels
T = torque of engine in lb.-in.
W = total weight of the truck, including the load, in lb.

In the case of a 1-ton speed-truck geared 5.625 to 1 and having a total weight of 5700 lb., the engine should have a torque of 1500 lb.-in. By reason of the light rolling characteristics of a properly designed vehicle of this class and because of the high average speed, it is possible for such a truck to climb on high gear short hills much steeper than the formula would indicate.

One of the great advantages of the pneumatic tire lies in its increased traction. This makes it possible for a pneumatic-tired speed truck to go into a farm field after its load. Because of this advantage the pneumatic-tired truck can operate in oil fields, timber tracts and the like, where the solid-tired truck would be helpless. Therefore, we must provide sufficient power on low gear to take advantage of this traction. The coefficient of friction between a pneumatic tire and the ground will not exceed 0.40 except on hard, rough surfaces, such as worn macadam. Obviously, extreme power is not needed on such a surface. If the wheels can be turned under conditions that require heavy torque, as in loose gravel, sand and mud, we will have provided all the low-gear ability that can be used. We have found that, on low gear, a tractive effort at the ground equal to 40 per cent of the

weight on the rear wheels is required. This is based on actual known delivered power.

Maintenance and Operating Costs

Low maintenance and operating costs are sought in all classes of vehicles and their value has been one of the weaknesses of the light delivery-trucks previously in the field. This indicates the necessity for a special effort toward improvement. We still have much latitude in this direction. The ordinary well built truck costs, during its life, six to eight times its original purchase price, for maintenance, operation and driver hire. Therefore, operating and maintenance costs must be given paramount consideration. Records show that it costs from 4.5 to 10.0 cents to move 1 ton of gross weight 1 mile, so that a saving in chassis and body weight is very important. Other things being equal, a saving of only 500 lb. will mean a saving to the user of from $1,100 to $1,800 during a truck life of 100,000 miles. Maintenance costs can be reduced materially by giving proper attention to the vital matter of cushioning truck parts against shocks and strains. This implies not only better springing, but also the use of shock-absorbing features of design throughout the chassis, such as the Hotchkiss drive, resilient frame members and flexible-fabric universal-joints. It is obvious that if the working parts are cushioned so that the brunt of road shocks is absorbed, the life of all such parts will be increased proportionately and the maintenance cost reduced.

There is no reason a loaded speed-truck should not ride more easily than a passenger vehicle. The load on the front end is so nearly constant that the springs can be made very flexible. The loaded rear-end weight above the springs is about six times the unsprung weight, while the ratio on the heaviest passenger cars is only about four. Even when running light, this ratio is about 3 to 1 for the speed-truck. With proper attention to spring suspension the speed-truck should be very easy riding and consequently easy on tires, the load, the road, the driver and the working parts of the chassis.

Equipment and Gear Ratios

The pneumatic tire permits the use of electrical equipment with perfect satisfaction. This equipment has not been accepted generally for solid-tire trucks because of the possibility of trouble due to the excessive vibration. The speed-truck will be used at all hours and operated at speeds requiring the best of lights. It will be employed in service in which numerous stops are necessary and must carry electric lights and an electric starter. A speedometer also is a necessity, because there is no governor to hold the vehicle within the legal speed limit. Power tire-pumps should be fitted on all trucks going into communities where free air-service is not available; for tires of 6-in. or larger cross-section they must be installed in all communities, as ordinary curb stations do not carry sufficient pressure to inflate these large tires properly.

Attention should be given to the problems of steering, brakes and final drive. Due to the speed, the steering and brake apparatus must be heavier in construction than that used on solid-tired trucks. To stop a truck running at 30 m.p.h. requires four times the braking effort required to stop one running at 15 m.p.h.

High axle-ratios are desirable and should probably be between 5 to 1 and 6 to 1 for a 1-ton vehicle. These ratios are well within the possibilities of spiral-bevel-geared axles. Since these axles are simpler, lighter and more efficient than other suitable drives, they undoubtedly will dominate this field, at least within the sizes named.

While the general success of the pneumatic tire in the larger sizes required on 3 to 6-ton trucks has still to be proved, there can be no doubt that their popularity on light speed-trucks will stimulate better cushioning in the larger trucks. More heavy trucks are discarded as a result of damage from excessive road vibration than of worn-out parts. The static loads on the working parts of a large solid-tired chassis are so small as compared with the shock loads, that breakage would be almost out of the question if the shock loads could be eliminated. There are many possibilities for increasing speed even in the largest vehicles without increasing this destructive vibration. Cushion tires and cushion wheels are being developed and promise excellent results. Better spring suspensions can be used. The driving line between the engine and the tires can be fitted with shock-absorbing universal-joints and engines can be mounted so that vibration from this source will be reduced materially. These points are mentioned to show that speed possibilities are not limited entirely to the light truck.

I emphasize the need for fast, economical, mobile trucks, particularly in the general-purpose sizes up to 2-ton capacity. It seems that these vehicles should combine speed, easy riding qualities, economy, durability and good performance. This requires a staunch well balanced engine; a transmission affording amply low gear-reduction; a rear axle of simple but rugged design; a light pressed-steel frame; effective brakes and good spring suspension. These units must be merged properly into a simple well balanced design.

To illustrate further the need for such trucks and why it has not been possible before to build large trucks for high speed, I refer to the photographs and drawings and their context in my paper, Cushioning in Motor-Truck Design,[2] at a previous meeting of the Mid-West Section.

THE DISCUSSION

Lon R. Smith:—To show the uses and the demand for a truck of, say, 1-ton capacity, I will read a summary made by P. J. Dasey of bulletin 910 published by the United States Department of Agriculture. It is obvious that the demand for small trucks is greater than for vehicles of large capacity, but just what capacity light truck is in greatest demand is open to question. The bulletin deals only with trucks used on farms in the States enumerated in Table 1; data regarding size and type of farm are presented in Table 2. Questionnaires were sent to 9659 farmers who owned trucks and 2314, or 24 per cent, replied. All second-hand trucks or motor units transformed into trucks, as well as all trucks owned less than six months, were excluded from the tabulation. Another 30 per cent was excluded because owners had sold their trucks, used them in commercial work only or not answered the questions in sufficient detail.

Summary of Department of Agriculture Bulletin No. 910.

The farms are of all sizes and types. The motor trucks used on them are of all sizes from ½ to 5 tons; very few have a rated capacity of over 2 tons; nearly half are of the 1-ton size.

Only 18 per cent of the farms are less than 5 miles and nearly 25 per cent are 20 miles or more from market.

Of these farmers, 95 per cent believe that their trucks will prove to be profitable investments.

Most farmers prefer the 1-ton truck to any other

[2] See The Journal, August, 1921, p. 143.

size. About 50 per cent of the owners of ½ and ¾-ton trucks prefer larger sizes.

In the opinion of these men the principal advantage of a motor truck is in saving time; and the principal disadvantage is poor roads.

They say that the trucks save from one-half to two-thirds of the time that would be required for hauling materials to and from the farms with horses and wagons; and that they have return loads for their trucks on about one-fourth of the trips.

A majority still use horses for some road hauling and, on most farms, all the hauling in the fields and around the buildings is done with horses. About 25 per cent of the men do some custom hauling with their trucks. The average annual amount received by those who do such work is $174.

For an average of about eight weeks in the year, the roads are in such bad condition on account of mud or snow that the trucks cannot be used; 75 per cent of the trucks usually travel on roads that are all or part dirt.

About 25 per cent of these men have changed their markets, for at least a part of their produce, since purchasing trucks. For those who have changed their market, the average distance to the old market is 7 miles, and that to the new market 20 miles.

TABLE 1—LOCATIONS OF FARMS

State	Number of Reports Tabulated
Maine	11
New Hampshire	11
Vermont	16
Massachusetts	63
Rhode Island	16
Connecticut	17
New York	241
New Jersey	92
Pennsylvania	235
Delaware	11
Maryland	40
Total	753

According to estimates by the owners, each of these trucks travels an average of 3820 miles per year and is used on 173 days per year.

The average estimated life of the trucks is between 6½ and 7 years; in most cases depreciation is the largest single item of expense.

Most of the owners of the ½ and ¾-ton trucks prefer pneumatic tires; the owners of 1-ton trucks are about evenly divided in their preference, but most owners of trucks larger than 1-ton prefer solid tires.

Over 66 per cent of the trucks had not been out of commission, when needed, for a single day in the year covered by the reports. Nearly the same proportion of the owners stated that they had not lost any appreciable time on account of engine or tire trouble or breakage; however, about 1 of every 30 trucks had been out of commission 10 days or more.

The average cost of operation of the ½-ton trucks was about 8 cents per mile; of the ¾-ton trucks, about 13 cents; of the 1-ton trucks, about 12 cents; of the 1¼ and 1½-ton trucks, about 19 cents; and of the 2-ton trucks, about 20 cents.

The average cost of hauling crops, including the value of the driver's time at 50 cents per hr., was about 50 cents per ton-mile with the ½-ton trucks; 34 cents with the ¾-ton; 26 cents with the 1-ton; 24 cents with the 1¼-ton and 1½-ton; and 18 cents with the 2-ton trucks.

About 80 per cent state that the trucks save hired help; they estimate that this saving amounts to $324 per year as an average.

About 50 per cent decreased the number of work animals by at least one head after purchasing trucks; however, less than 1 man in 10 disposed of more than two head. Over 50 per cent of the men whose farms contain more than 120 crop-acres own tractors. The number of work animals kept on the farms where both trucks and tractors are owned is only slightly less than the number kept on the farms of corresponding size where only trucks are owned.

TABLE 2—TYPES OF FARM AND ACREAGE

Type of Farm	Total Number	Average Size, acres
Truck	149	64
Dairy	129	234
Fruit	113	111
Crop	48	237
General	314	210
Total	753	...

The different sizes of truck owned are stated in Table 3, as well as what sizes are considered best. These figures should be of value to everyone interested in the manufacture and sale of trucks. They point to the truck capacities best adapted to farm requirements, to the possibilities of sales of larger trucks to the present users of smaller ones, and to sales of smaller trucks to the present users of larger ones.

I suppose we have all considered that the 1-ton size is especially suitable for merchants; it was my opinion also that a somewhat larger truck than the 1-ton size was what the farmer was buying. I was surprised to find evidence in this report that the 1-ton truck seems to be in greatest use and most preferred.

G. A. WEIDELY:—Regarding the future of the high-speed pneumatic-tired truck, about two years ago it appeared that the large trucks would get most of what is known as the short-haul business, particularly in districts having so-called improved roads. For example, a company was organized to do a trucking business between Cleveland and Detroit and a number of similar companies were organized throughout the country. But they discovered that the roads would not hold up. The road from Toledo to Detroit is a fair example of that. We know that the pneumatic-tired 1 and 1½-ton trucks will run on bad roads at a fairly good speed, but that the 3 to 5-ton trucks cannot do this. It is likely to be 8 or 10 years before the various Governmental authorities learn how to build roads that will stand up under heavy-truck traffic. Until that time there should be a good field for the small high-speed truck.

B. F. KELLY:—What do these farmers mean by a 1-ton truck? I believe that the 1-ton truck Mr. Guernsey has in mind will carry much more load than the average 1-ton truck that the farmers report.

MR. WEIDELY:—The statistics quoted have to do with what the farmer wants. That is not necessarily the truck Mr. Guernsey mentions. The farmers wants a 1½-ton truck, one of 3000-lb. carrying capacity, or about the capacity of the present-day two-horse wagon universally used on the farm.

MR. KELLY:—That again is misleading. The farmer is accustomed to load 60 bu. of corn into his wagon, which,

TABLE 3—TRUCK SIZES OWNED AND SIZE CONSIDERED BEST

Number of Farmer Owners	Truck Size Owned, tons	Size Considered Best, Number of Votes
131	½	48
83	¾	62
329	1	329
63	¼ or ½	113
77	2	115
13	2½	...
...	2 and over	29
Total 696	.....	69[illegible]

I believe, is a 1½-ton load. If that is attempted on some 1-ton trucks they will break.

MR. SMITH:—This bulletin is interesting because it covers the average load that these farmers carried on trucks of different capacity, and it at least gives a good idea of what the farmers in New England and Atlantic Coast States do with their trucks. I think it constitutes a fair criterion by which to judge the work of any user.

CHARLES O. GUERNSEY:—One of the farm journals circulated a questionnaire letter in Iowa, Illinois, Indiana, Idaho and the Dakotas, and received about the same percentage of replies as was mentioned in connection with bulletin 910. It was indicated that the farmers who had trucks above 1½ or 2-ton capacity wanted smaller ones and that those who had trucks of 1-ton or smaller capacity were interested in larger trucks. But the farmer is not willing to pay the price of a heavy truck, such as a conservative truck builder would rate at 1½ or 2-ton capacity. We have designed two high-speed trucks. One is of 1½-ton capacity and fairly heavy, with good factors of safety all through; perhaps it can be rated as of 2-ton capacity without causing trouble, but, because of its weight, the tire sizes and the power required, it costs so much that the farmer will not pay the price. The farmer will probably buy the 1-ton truck and haul 1½ tons, or whatever load he can put on it, and consider himself satisfied. The rating of trucks is variable because no two men design trucks alike. One firm is more conservative than another; a truck that one company rates as 1½-ton another might rate as 3-ton.

Mr. Weidely gave a good illustration of what happens to present-day roads under heavy-truck traffic. The roads, as they are built now, will not withstand the use of heavy trucks at high speeds. If they were kept down to a speed of 10 m.p.h. it would be all right, but it is difficult to hold the truck owner within the proper speed and load limits. The result is that a terrific impact is produced on the road.

G. A. WAHL:—The difference in vibration of trucks equipped with solid and with pneumatic tires was brought to my attention in 1917 by tests made at Langley Field by Col. A. J. Slade with two each of four different makes of trucks ranging from about 2½ to 3-ton capacity. The trucks were filled with iron bars and run over a solid road that was in bad condition. At 12 m.p.h. the solid-tired truck vibrated considerably more than the pneumatic-tired truck at 22 m.p.h. At slightly over 15 m.p.h. it was impossible to keep the iron bars in the solid-tired trucks, whereas at 22 m.p.h. there was very little movement of these bars in pneumatic-tired trucks. This was only a relative and a very crude comparison in some respects, but it showed the great amount of vibration that the truck had to endure when equipped with solid tires. There is no question that good roads are of as much importance as having trucks properly equipped. The solid-tired truck damages roads, but generally speaking the pneumatic-tired truck also causes damage at a speed of say 30 m.p.h. In the tests referred to the tractive power of the trucks in a soft field was noted, the wheels sinking into the ground about 10 or 12 in. It was surprising to find that there was practically no difference between the tractive efficiency of the pneumatic and the solid tires.

CHARLES A. TRASK:—What has been done toward regulating the tire width in relation to the total load? I have heard that township officials in the northern part of Indiana had some truck owners arrested recently for carrying such heavy loads on comparatively narrow tires that they were ruining the roads. If there are to be no regulations of this kind, it will never be possible to build roads that will endure. If 2-in. tires were put under a 10-ton truck, they would ruin any road that can be constructed, unless it were made of steel. I hope for some regulation that will compel the use of wider tires. What data have been obtained regarding a restriction of the load based on tire widths or size?

MR. GUERNSEY:—If every State presumed to legislate on this subject to suit its own needs, we would have to design trucks differently for every State in the Union to meet all requirements. In general it is conceded in many important States that 1 in. of nominal tire width is ample for each 800 lb. of load on a wheel.

A MEMBER:—Can a battery be made large enough to start a truck engine as often as is necessary in delivery service?

MR. GUERNSEY:—We have had no trouble as yet. When making frequent starts and stops, the engine is warm enough to start easily.

MR. SMITH:—We made some investigations with the idea of determining what market there was for the various sizes of our product. We used data published by the National Automobile Chamber of Commerce and by various periodicals, included our own data and compiled a table to learn how many trucks of different capacities were being built. This table checks up with the research work of the Department of Agriculture and with what Mr. Guernsey says. In 1919, 130,368 trucks were produced by organizations other than those who build their own engines, of which about 12,000 were ½-ton trucks; nine firms construct that size. About 6000 ¾-ton trucks were produced by 10 companies and 59 firms built 1-ton trucks to the number of 38,000 in 1919. The next popular size was the 2-ton truck, constructed by 71 firms; and 21,000 trucks of 1¼ to 1½-ton size were turned out by 98 different companies.

L. A. CORCORAN:—Due to the fact that a small fast truck is needed, I believe that manufacturers are resorting to the use of pressed steel in place of cast iron to cut down the weight and get practically the same strength.

MR. GUERNSEY:—That depends largely on the volume of the plant's production. In our own case there is a very decided tendency toward pressed steel and forgings to replace castings. Weight can be saved in many ways, of which changing from solid to pneumatic tires is one.

The Motor Transport Corps made an analysis of axle-center design for front axles during the war. In the case of solid-tired trucks it was ordinary practice to assume a static load of about 8000 lb. per sq. in.; in the case of passenger cars it was found that this static load advanced from 10,000 to 15,000 lb. per sq. in. and a number of very good cars averaged 12,000 lb. per sq. in. That would indicate for unsprung parts when trucks are built for pneumatic tires a saving in weight of one-third, but that cannot be carried out generally because of foundry or shop-practice limitations. In frame design for solid-tired trucks we must make the frames heavy enough to withstand the vibration and shocks to which I referred, while for pneumatic tires we take a higher figure for the stresses. So, we can actually save weight by a lighter design, in addition to adopting various other lighter parts, such as those made of pressed steel.

The Nature of Flame Movement in a Closed Cylinder

By C. A. Woodbury[1], H. A. Lewis[2] and A. T. Canby[2]

Annual Meeting Paper

DR. HAROLD B. DIXON, of the University of Manchester, the eminent English authority on combustion phenomena, has submitted a very interesting discussion of this paper, which was presented at the 1921 annual meeting of the Society. This discussion and the reply received from Mr. Woodbury are given below together with comments made by F. W. Stevens of the Bureau of Standards. For the convenience of the members a brief abstract of the paper precedes the discussion.

ABSTRACT

THE nature of flame propagation in an automobile engine cylinder has, for some time, been the subject of much discussion and speculation. However, very little experimental work has been done on flame movement in closed cylinders with a view to applying the knowledge directly to the internal-combustion engine.

It has become recognized that knocking is one great difficulty which attends the use of the higher-boiling paraffin hydrocarbons, such as kerosene, and that knocking is one of the major difficulties to be overcome in designing higher-compression and hence more efficient engines. It was desirable, therefore, to determine, if possible, the nature and cause of the so-called fuel knock in an internal-combustion engine.

The work described in this paper was undertaken to determine the characteristic flame movement of these various fuels and the physical and chemical properties which influence this flame propagation. The scope of the work is specified and the arrangement of the apparatus for measuring flame propagation is illustrated and described. Flame movement at normal temperature and pressure was then investigated, the results obtained are shown in charts and a table and these are commented upon in detail. The influences of turbulence and of temperature and pressure on flame propagation are treated in like manner, followed by a lengthy discussion of autoignition and the nature of fuel knock, which also is illustrated. [Printed in the March, 1921, issue of The Journal.]

THE DISCUSSION

Dr. H. B. Dixon:—The paper is naturally of great interest to me, for I have been working on the theory of the explosion of gases for more than 40 years, and during the last 3 years have been experimenting on the combustion of the vapors of pentane, hexane, benzene, alcohol and ether with the object of obtaining data that might be useful to the designers of internal-combustion engines.

About 20 years ago I took photographs on a moving film of explosions in strong glass cylinders 9 in. long by 2½ in. internal diameter, fitted at one end with a delicate pressure indicator, and so obtained records of the spread of the flame and of the pressures registered after the passage of the spark, which itself was recorded both on the photographic film and on the pressure-card. The negatives, though fairly visible during development, made poor prints, and the pressure curves, owing to the inertia of the piston used, were comparable only for explosions that traveled at about the same rate. The photographs showed the increase in luminosity and velocity as the flame traveled from the ignition-point; they also showed the marked effect on the flames of the position of the spark, whether at the end of the cylinder, i.e., flush with the end-wall, or at a short distance from it. The indicator showed that the piston began to move when a pressure-wave starting from the beginning of the explosion was calculated to reach the piston after traveling with the velocity of sound through the unburnt gases ahead of the flame. I did not publish these results, but proceeded to attack each part of the problem separately. After my experience I can congratulate the American experimenters on the skill with which they have combined the photographic records of the movements of the flame and the variations of pressure in the explosion vessel.

In discussing the results arrived at by the authors, I may say that I am in cordial agreement with their main observations and conclusions that

(1) When acetylene-air mixtures are fired by a spark at one end of a closed cylinder, the average velocity of the flame is greatest when the acetylene forms between 8 and 10 per cent of the mixture, and when acetylene-oxygen-nitrogen mixtures are fired an explosion-wave or detonation is set up most readily when the oxygen is just sufficient to burn the carbon to monoxide and the hydrogen to steam, an excess of oxygen acting as inert gas

(2) When fired in closed vessels the flame travels with increasing velocity from the spark, but is usually checked before it reaches the end of a short tube or cylinder

(3) If the flame travels toward the end of a tube drawn out into a hollow cone the pressure may be piled up, as in the case of a tidal bore in a narrowing estuary, until even mixtures of relatively high ignition-point can be fired ahead of the advancing flame by the heat of compression. It has been shown in the *Proceedings of the Royal Society of London* that hydrogen and oxygen can be fired in this way

(4) It is not easy to set up an explosion-wave or detonation in a short cylinder, although acetylene and ethylene will detonate with air when fired in a long tube; and I do not believe that the "knocking" or "pinking" heard in gas engines is due to a true explosion-wave. In the explosion-wave the flame is traveling through unburnt gas at a constant velocity that is twice that of sound in the burning gases. Behind the wave-front the gas is moving forward en masse with the velocity of sound, and the wave-front is traveling forward with the velocity of sound in this moving medium. This statement admits of an easy confirmation, for if a sound-wave or compression-wave is made to travel through the burning gases immediately behind the wave-front and in the same direction while the explosion is photographed on a moving-film the sound-wave traces a line which is practically par-

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allel with the line of the explosion-wave, i. e., it is traveling forward through the burning gases with the same velocity as the explosion-wave. In a photograph published in the *Philosophical Transactions of the Royal Society of London*[3] the sound-wave was started too far behind the wave-front to move forward with the same velocity as the medium in which it was moving had begun to slow down; later photographs have shown that the nearer the sound-wave is to the wave-front the more nearly does it equal it in speed

In agreement with their first conclusion I have found[4] that when the explosion-wave is propagated through acetylene-oxygen mixtures there is an increase in the rate of the explosion when the oxygen is reduced from 2½ to 1½ times the volume of the acetylene, and similarly in the case of ethylene-oxygen mixtures. Moreover, the replacement of the "extra" volume of oxygen by an equal volume of inert nitrogen has a less retarding effect on the rate, as is brought out in Table 1.

TABLE 1—RATE OF PROPAGATION OF EXPLOSION-WAVE

Mixtures	Rate of Propagation Meters per sec.	Miles per sec.
Acetylene Mixture		
$2\ C_2H_2 + 3\ O_2$	2,716	1.687
$2\ C_2H_2 + 3\ O_2 + 2\ N_2$	2,414	1.500
$2\ C_2H_2 + 5\ O_2$	2,391	1.486
Ethylene Mixtures		
$C_2H_4 + 2\ O_2$	2,581	1.604
$C_2H_4 + 2\ O_2 + 2\ N_2$	2,413	1.499
$C_2H_4 + 3\ O_2$	2,368	1.471

It is an inference from these, and from similar results obtained with other carbon compounds, including pentane, benzene and alcohol, that the original burning of the carbon resulted in the formation of carbon monoxide; probably in some cases with the momentary existence of an intermediate body which breaks up as shown in the reactions below

$$C\,H_4 + O_2 = H_2\,C\,O + H_2\,O$$
$$H_2\,C\,O = H_2 + C\,O$$

The carbon monoxide formed, directly or indirectly, would then react, in the absence of free oxygen, with the steam, and an equilibrium would be reached as the gases cooled

$$C\,O + H_2\,O \leftrightarrow C\,O_2 + H_2$$

In the case of cyanogen the evidence is more direct. When the explosion-wave is propagated through the mixture in equal volumes the carbon is found, almost entirely, as carbon monoxide, and the rate of propagation and the violence of the explosion are both much greater than in the mixture with two volumes of oxygen when the carbon is found in the residual gases as carbon dioxide.

Again when a volume of nitrogen is added to the mixture in equal volumes, $O_2N_2 + O_2$, it has a less retarding effect than an equal volume of oxygen, as would be the case if both were inert in the primary combustion. Later experiments with nitrogen and argon as diluents have shown me that when the cyanogen-oxygen mixture is damped down by an inert gas the rate of the explosion-wave is not independent of the diameter of the tube, and the wave travels faster in a straight pipe of 19-mm. (0.748-in.) bore than in one of only 9 mm. (0.354-in.); but this does not affect the comparative damping effect of the nitrogen and oxygen added.

One obvious explanation presents itself, and I think it is the correct one, that carbon dioxide, if directly formed in the explosion-wave of cyanogen with two volumes of oxygen, would be dissociated at the high temperature produced. If this is the explanation it follows that the carbon dioxide found in the analysis of the residual gases from the exploded mixture, and practically all the carbon is found as the dioxide, must have been formed behind the wave-front, or while the gases were cooling. There would be consequently a longer column of reacting gases behind the wave-front since the cooling would be retarded by the gradual burning of the carbon monoxide to dioxide. That there is such a longer column I have verified by two methods, that of the "jet" and that of the "window."

In the first photographs were taken of the jets of flame thrown out from a long tube in which the two mixtures were detonated, the tube being opened just before firing. When the cyanogen was fired with two volumes of oxygen the jet photographed was much longer and more luminous than when fired with one volume of oxygen. The jet is thrown out only after the flame-front has traversed the whole column of combustible gases. In the latter method photographs were taken on a rapidly moving film of the illumination of a small window in a tube as the explosion-wave passed. When the cyanogen was detonated with one volume of oxygen the illumination was much brighter but much shorter in duration than when fired with two volumes of oxygen.

The slight lowering of the velocity of the flame of acetylene-air mixtures found by the authors, when the initial temperature was raised at constant pressure from 25 to 125 deg. cent. (77 to 257 deg. fahr.) was what I should have expected from my experiments. It was shown, for example, that the ignition-point of electrolytic gas[5] when fired by compression is the same, 526 deg. cent. (978.8 deg. fahr.) whether the gases were originally at room temperature or at 100 deg. cent. (212 deg. fahr.), although of course less compression was required to fire the gas at the higher temperature. Again the explosion-wave[6] is propagated through gas mixtures at slightly lower velocities when the gases are initially heated at constant pressure to 100 deg. cent. (212 deg. fahr.), as shown in Table 2.

TABLE 2—RATE OF PROPAGATION OF EXPLOSION-WAVE

Mixture	$2\ H_2 + O_2$	$C_2H_4 + 2\ O_2$	$C_2N_2 + O_2$
Rate at 10 deg. cent., meters per sec.	2,821	2,581	2,728
Rate at 50 deg. fahr., miles per sec.	1.758	1.609	1.695
Rate at 100 deg. cent., meters per sec.	2,790	2,538	2,711
Rate at 212 deg. fahr., miles per sec.	1.734	1.577	1.746

With regard to initial changes of pressure, Dr. Coward and I found that when hydrogen and oxygen are heated separately and then brought together, the ignition temperature is only slightly raised from about 590 deg. cent. (1094 deg. fahr.) at atmospheric pressure to 600 deg. cent. (1112 deg. fahr.) by halving the pressure; while by doubling the pressure it is lowered more appreciably to about 560 deg. cent. (1040 deg. fahr.).

Experiments on the velocity of the explosion-wave show that it is propagated at a slightly increased rate with in-

[3] See the *Philosophical Transactions of the Royal Society of London*, vol. 200A, plate 12, fig 23.

[4] See the *Philosophical Transactions of the Royal Society of London*, vol. 184, p. 120.

[5] See *Journal of the Chemical Society* (England), vol. 105, p. 2046.

[6] See the *Philosophical Transactions of the Royal Society of London*, vol. 184A, p. 108.

creased initial pressure, as is brought out in Table 3, but a maximum rate seems to be reached soon.

TABLE 3—RATE OF PROPAGATION OF EXPLOSION-WAVE AT DIFFERENT PRESSURES

Mixtures	$2\,H_2 + O_2$	$C_2H_4 + 2\,O_2$
500 mm., meters per sec.	2,775	2,280
19.685 in., miles per sec.	1.724	1.417
760 mm., meters per sec.	2,821	2,322
29.921 in., miles per sec.	1.758	1.443
1000 mm., meters per sec.	2,850	2,319
39.370 in., miles per sec.	1.771	1.497
1500 mm., meters per sec.	2,872	....
59.055 in., miles per sec.	1.786	....

The reason an increase of 100 deg. cent. (212 deg. fahr.) in the initial temperature of the gases at constant pressure has but a small effect on the propagation of the flame is probably that the temperature of the reacting gases is but little altered.

If a gas mixture has an ignition-point of 600 deg. cent. (1112 deg. fahr.) it means that at this temperature the gases begin to heat up automatically by a flameless combustion, which increases in rate until at some high temperature, probably well over 1000 deg. cent. (1832 deg. fahr.) the flame appears[7]. With many gas mixtures the rate of combination a few degrees below the ignition-point is negligible; chemical action is slow in the pre-flame period of combustion, and only becomes rapid with the appearance of the flame itself. If the initial temperature of the gas is raised 100 deg. cent. (212 deg. fahr.) this rise is not added to the flame-temperature, but only, by giving the system a "push-off," allows the flame-temperature to be reached a little earlier. However, when the temperature of the burning gases is increased, by the passage of an intense pressure-wave through the flame, the effect on the combustion may be strongly marked, and when gases are fired by adiabatic compression the spread of the flame is as a rule more rapid, and the explosion-wave, if it can exist, is more rapidly set up than under normal temperature and pressure conditions.

Many of my photographs show, by delicate striæ, the forward movement of the gas behind the wave-front, the gradual arrest and the backward movement which takes place independently of any reflected or other pressure waves. The striations, however, become much more marked when pressure-waves are reflected backward and forward through the burning gases.

Origin of the Pressure-Waves Crossing the Burning Gases

There are several sources of pressure-waves that may be propagated through the burning gases in an explosion:

(1) The explosion-wave, set up after a certain distance of travel in a long tube, may strike the end of the tube and be reflected backward. Its rate and intensity depend on the nature of the burning gases. For instance, when cyanogen is exploded with its own volume of oxygen the chemical reaction is very rapidly completed.

$$C_2N_2 + O_2 = 2\,CO + N_2$$

The reflected wave has therefore to travel the greater part of its journey through gases in which the chemical action is little or nil. But when cyanogen is fired with twice its volume of oxygen the flame lasts much longer owing to the carbon monoxide, produced in the primary reaction, forming carbon dioxide as the gases cool.

$$C_2N_2 + 2\,O_2 = 2\,CO + O_2 + N_2$$

$$2\,CO + O_2 + N_2 = 2\,CO_2 + N_2$$

The reflected waves in this mixture are more strongly marked

(2) At the point where the explosion-wave is set up there is propagated backward a pressure-wave which I termed the retonation-wave. This resembles in many respects the reflected wave from the explosion-wave. It is easy to choose a mixture of gases of such a kind and a tube of such a length that the explosion-wave or detonation is set up just at the moment when the flame reaches the end of the tube. There is no unburnt gas to carry forward the explosion-wave, but the retonation-wave is sent backward and the reflected-wave is superposed on it, so that the pressure-wave moving backward through the only partially burnt gas is almost identical at first with the explosion-wave in velocity and violence[8]

(3) A pressure-wave, traveling with the velocity of sound in the unburnt gas, is propagated from the point where the explosion is initiated by the spark or by a small detonator. This pressure-wave traveling at constant velocity will be overtaken by the flame with its accelerated motion, if there is sufficient length of run; but if the tube is short the pressure-wave reaches the end of the tube first, and is reflected backward so as to meet the advancing flame, which, as I read the photographs, is retarded and even thrown back in some cases for a space, while the pressure-wave is being propagated backward through the burning gases, its course being now faster and marked by increased light

If the tube is of such a length that this initial pressure-wave and the flame reach the end of the tube at the same instant, the reflected waves of both are superposed, and the combined wave is comparable with a retonation-wave. This, I think, is the commonest cause of "knocking" in an explosion cylinder.

A retonation-wave might be set up at the same instant that the flame and the initial pressure-wave reached the end of the tube together. If this were to happen the combined return-wave would hardly be distinguishable from a detonation. The American experimenters differ from me as to the cause of the arrest of the flame before it reaches the end of the cylinder, and as to the source of the pressure-wave proceeding from that point. We are agreed that something runs up against the flame, or the flame runs into something that checks it suddenly. I attribute this to a pressure-wave, started by the initiation of the explosion at the spark, and continually "backed up" by the moving flame gathering speed behind it. The front of this column of high pressure, with the gas moving bodily in its wake, is reflected from the end of the tube. Whatever it is, it is traveling with the velocity of sound in the unburnt gas; I have found this to be true with gases varying in vapor density from that of electrolytic gas, 6, to that of cyanogen with an equal volume of oxygen, 21. The authors attribute the arrest of the flame to the equalization of pressure in front of and behind the flame: "When the pressure is equal the flame-front is no longer pushed forward; the propagation is arrested." They observe that the equalization of pressure should be a gradual process and they would expect the arrest of the flame to be gradual rather than sudden, as it is. But if the advance of the flame is not checked by a pressure-wave accompanied by a backward movement of the gas, I cannot understand why the flame should not

[7] See *Journal of the Chemical Society* (England), vol. 106, p. 2033.

[8] See the *Philosophical Transactions of the Royal Society of London*, vol. 200A, plate 15, figs. 44 to 51.

proceed through the high-pressure area with undiminished velocity, since high pressure, unaccompanied by movement, has little influence on the rate of propagation. The backward movement of the gas is made visible by the striæ in the flame as the pressure-wave passes backward through the burning gas, but this backward movement and the pressure-wave itself are caused, according to the authors, by the arrested flame itself.

Let me refer to a photograph that my colleague, Dr. Campbell, has recently taken and is reproduced in the lower left corner of Fig. 1. An explosion-wave has been propagated through a mixture of cyanogen, oxygen and nitrogen in a narrow tube opening into a wide one. The flame is traveling from right to left while the film is moving vertically downward. The explosion-wave is damped down soon after the flame emerges into the wider vessel, at the point marked by the white arrow, but it sends forward through the unburnt gases an intense pressure-wave which, leaving behind the slackening flame, reaches the end of the wide tube first and is reflected from it. On drawing the path of this pressure-wave from the calculated velocity of sound in the gases, it is found, within the limit of error, to strike the advancing flame at the point *A* where the flame is arrested. The flame is driven back and the striæ show that the gas itself is moving backward in the wake of the pressure-wave until the latter strikes the end-wall through which the narrow tube debouches. The wave penetrates the narrow tube, forming a line of light just visible at *B*, but the greater portion is reflected from the wall and is seen proceeding forward again from right to left until it reaches the flame-front at *C*, near the second black reference line. The flame-front is now pushed forward again, but the pressure-wave, suffering a slight reflection which is visible in the photograph, where it meets the flame-front, passes into the unburnt gas ahead of the flame, is again reflected and arrests the flame a second time at *D*, where it again passes backward through the flame, reproducing its previous action. The two points of arrest, *A* and *D*, correspond, within the limit of error, with the point where a pressure-wave traveling with the velocity of sound through the unburnt gas would meet the flame.

In the photograph shown in the upper left of Fig. 1 the explosion was started simultaneously at the two closed ends of the tube. The spark on the right being more intense caused the flame on that side to start faster than the flame on the left. An initial pressure-wave runs forward from each side, that from the right traveling farther before it meets the slower-moving flame on the left. We can see where it meets and throws back the left-hand flame, passes through it and is reflected from the closed end. On its return it checks the backward movement of the left-hand flame and hurries it forward again. Passing now ahead of the flame it is invisible until it strikes the right-hand flame which it throws back sharply, and is propagated through it to the right-hand end. The right-hand flame has meanwhile been arrested by the initial pressure-wave from the left, which passing through it is reflected from the end-wall and in its turn hurries up the right-hand flame and checks the left-hand flame. The initial flames, not being symmetrical, give rise to pressure-waves of unequal intensity. The upper part of this photograph gives a pretty illustration of the coalescence of two waves, or rather the absorption of the weaker by the stronger wave.

The photograph shown in Fig. 1 at the right gives the movements of the flame in a mixture of hydrogen with three volumes of oxygen fired by a spark near the right side of the tube while the gases were being compressed by the sudden thrust of a piston from the left. At the moment the spark was passed the gas had been compressed to nearly one-quarter of its original volume, from a column of 24 in. in length to 6 in. and of course was heated up by the compression. The pressure-wave started by the initiation of the explosion reached the advancing face of the piston before the flame, and on reflection checked the flame near the broad black shadow thrown by the clamp and traversed the burning gases to the right-hand end. The peculiarity of this hitherto unpublished photograph is that the gas was ignited by the pressure-wave at the face of the piston, or possibly in an interstice between the piston-head, which was wrapped with silk thread, and the glass tube. The flame so started by compression did not advance quickly, although it was very luminous owing to the burning of a little lanoline used as a lubricant on the thread. It was easily outdistanced by the pressure-wave reflected from the face of the steel piston. The photograph shows the comparatively slow advance of the piston which was finally arrested by a collar when it had penetrated 3 in. farther. The tail of luminosity coming from below in the center of the picture is due to the remains of the lanoline still burning when the film, which was 1 meter (39.37 in.) long, had made a complete revolution.

It will be seen from this account that I agree with the authors of the paper that there is a column of high pressure driven ahead of the burning gases in the first phase of the explosion, and that this pressure causes the arrest of the flame in a short vessel. I differ from them, it seems, in that I think that the front of this column of high pressure reaches the end of the tube and is reflected from it. When the reflected pressure-wave meets the advancing flame it checks it by its bodily motion, and itself proceeds through the burning gases with an increased speed. Perhaps we may find that our difference is mainly one of expression. Many experiments have shown that this pressure-wave travels with the velocity of sound, and I have called it, perhaps wrongly, a "sound-wave," for short.

Nearly all my photographs show the "stratification" in the flame becoming more and more marked as the pressure-waves cross and recross the tube. Sometimes the striæ appear to be driven to one side or other of the tube, leaving dark spaces. This stratification is no doubt due to solid particles, minute fragments of glass and metal, and to particles of carbon, when carbon compounds were fired, raised to incandescence and thrown backward and forward by the movements of the gas they float in. The regularity of the stratification suggests an arrangement like the dust figures in Kundt's tube when the length of the tube is not an exact multiple of the wave length.

On one other point I think my results are at variance with the authors' conclusions. They state that "The instant of maximum pressure development coincides with that of total inflammation of the gas charge." If the authors mean by "total inflammation" the fact that the flame has spread from end to end of the vessel and that the whole column of gas is visibly alight, it may happen that the pressure is greatest at that moment, but in many cases, and I believe in most instances, the greatest mean pressure occurs after the flame has completely filled the vessel. A detonation-wave, as I have shown, may be on the point of starting when the flame reaches the end of the tube. As a result a retonation-wave superposed on a reflection-wave starts back through the burning gases, and its rapidity bears witness to the high temperature and high pressure produced in it. A pressure-

gage fixed at the end of the tube from which the retonation-wave starts back would of course indicate this high pressure, and it would coincide with the arrival of the flame, completing the "total inflammation." But the retonation-wave traversing the already burning gases would bring about increased chemical action, and raise the mean pressure of the whole column of gas after the "total inflammation." In many cases the pressure-waves crossing the vessel from end to end have the greatest rapidity, indicating the highest mean temperature and pressure, some time after the whole column of gas has been ignited.

The main difference between the initial phases of the explosion and the explosion-wave or detonation appears to lie in the rapidity of the chemical action. In the initial slow phase only a few of the collisions between molecules result in a chemical change; the flame therefore persists while the gradual burning proceeds and the luminosity is small. In the explosion-wave most of the collisions between suitable pairs of molecules result in a chemical change; the flame therefore is short-lived, except where dissociation occurs, and is intensely hot and luminous.

There is still much that requires elucidation in the explosion of gases, especially as to the temperatures reached. The mode in which turbulence acts is very important in regard to gas-engine practice. My colleagues and I are trying to get photographic evidence on this in the explosion of hydrocarbons, alcohol and ether. I may take this opportunity of correcting a statement I made last year, for we have now good records of the starting of explosions in mixtures of these vapors with oxygen and nitrogen, and find that alcohol is *not* the fastest off the mark, as we thought from our first faint photographs, but is rather a slow "starter" compared with its competitors.

F. W. STEVENS:—One cannot get away from the conviction that there is after-burning; that the flame phenomena do not include all of the reaction. It seems to me that the species into which a fuel may break up necessarily have different velocity-constants, and that in the rout of an explosion they will naturally take different positions along the road, the worst wounded and slowest being the longest on the way. Yet, if we interpret correctly the sound-waves passing through these gases behind the flame, they must be homogeneous, for they show constant velocity.

The only check I have observed or interpret from any of Doctor Dixon's figures is that due to the reflection of sound from the end of tube. At the start the apparent flame-velocity is made up of the velocity within the gas plus the mass movement of the gas itself. The reflected sound-wave checks this mass movement for a short interval, even making it negative; but has no other effect upon the progressive movement of the flame within the gas than that the momentary differences of pressure may affect its velocity, by a rise of temperature.

Temperature has a profound effect upon all chemical reactions. Over the range of about 100 deg. cent. (212 deg. fahr.) where the most of the observations have been taken, the change in the velocity-constant is about 30 per cent per degree. With high temperatures the percentage-change would fall; but it would still be largely below any of the ignition temperatures, from 500 to 700 deg. cent. (932 to 1292 deg. fahr.); for very high temperatures, reaction velocities seem to be proportional to the pressure; for reactions at lower temperatures, pressure, without a corresponding temperature rise, seems to have little effect.

Since the elastic properties of gases and their densities determine their wave motion, it is to be expected from

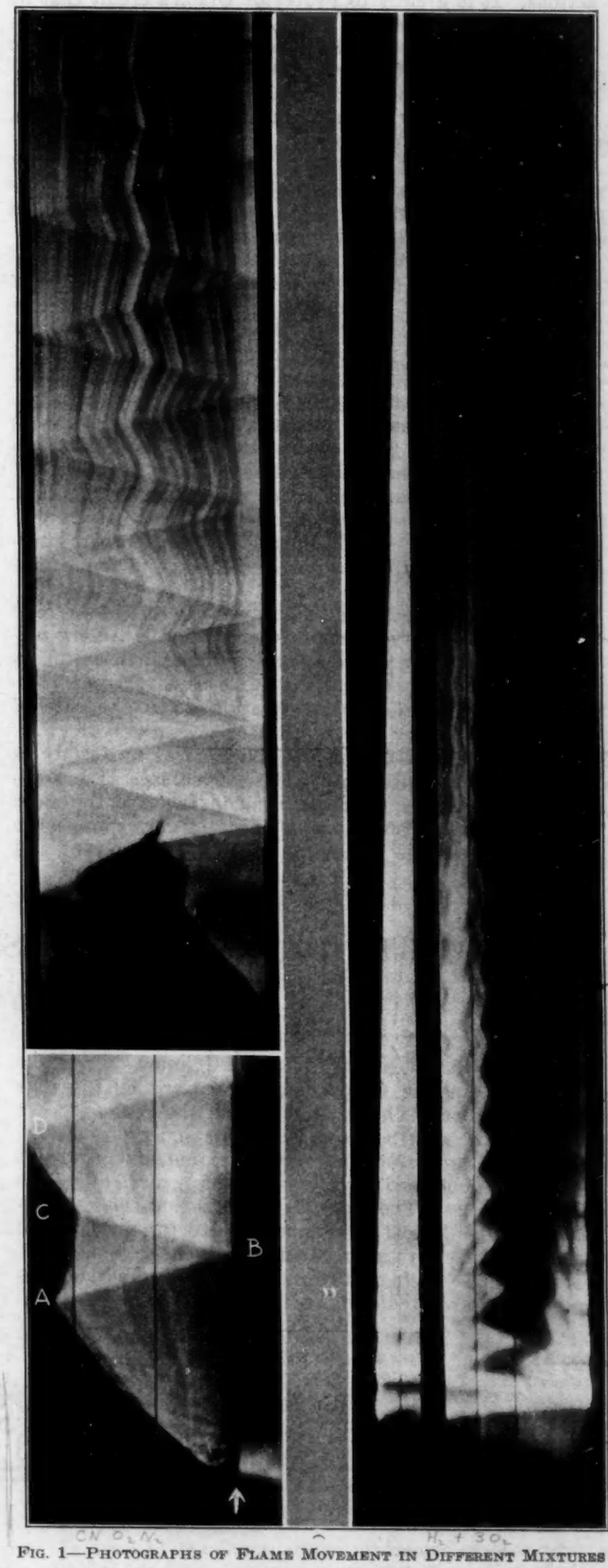

FIG. 1—PHOTOGRAPHS OF FLAME MOVEMENT IN DIFFERENT MIXTURES

thermodynamic considerations that their reaction velocities will be closely connected with their physical properties. It seems, in fact, impossible to separate these two actions. It is greatly to Professor Dixon's credit that he has emphasized these relations. I think there are some chapters on sound that have not been written. I have seen a very nice photograph showing a reflected sound-wave from the end of a tube, meeting a flame-front where it has nearly reached constant velocity, detonation. The effect of the compression is beautifully shown by the bright spots; from which the flame-front then proceeds at a constant velocity to the end of the tube. The sound-wave is refracted as it enters the highly heated and rarified gases behind this point.

The photograph in the lower left corner of Fig. 1 looks like a most beautiful and interesting demonstration of a mooted question in sound. If the two waves finally coalesce, then they travel at unequal velocity. Is that possible? There is a short interval between them. Is it possible that this short interval furnishes enough difference of temperature to bring them into phase? Such a process could be used to measure the rate of cooling in these incandescent gases with great accuracy. Has Doctor Dixon found a new differential thermometer here? If once brought to phase, the waves will not separate again. This photograph has as much interest for the student of sound as for the chemist. There are some other interesting things about explosions in reference to sound that could be cited.

I think the expression "flame velocity" is often used to mean the velocity of combustion, which is a very different concept. Manometer readings have little to tell us about flame movement, but they give us a very considerable amount of valuable information about the rate of combustion.

The law of mass action probably acts as uniformly in quick as in slow reactions. The convenience of observing whether this is so or not is all in favor of the more common chemical processes or those largely confined to solutions where the retarding effect of the solvent and of the small temperature-range gives ample time for observation and measurement.

It is really remarkable that the major part of our laws in chemistry, certainly in thermodynamics, has been drawn from what we have supposed to be the simplest state of matter, the gaseous; yet the chemical processes taking place in gases are the least explored and determined of all. Against the bulk of other chemical reactions that we know fairly well, the percentage of gaseous reactions is almost negligible. Until there is sufficient evidence to the contrary we should look for gaseous reactions to follow the same general course as all others. Guldberg and Waage's generalization calls for a condition of constant reaction velocity to be reached sooner or later in the reaction as determined by the driving force and those in opposition. Such a phase is one of the most characteristic properties of explosions. Berthelot was the first to point it out. Guldberg and Waage came to it as a generalization from the commoner reactions. The two are probably identical and follow the same laws throughout. Berthelot's attempt to identify these velocities with molecular velocities, doubtless following the inspiration of Clausius, is interesting; there seems to be some agreements, but the facts to draw from are meager. However well the lower limit of our thermodynamic scale seems established, the upper limit is not yet suggested. Gas reactions have a range through many thousand degrees; most reactions we are familiar with, through a few tens at most.

C. A. WOODBURY:—We were gratified to note the many points upon which our conclusions had coincided with those of Doctor Dixon. With regard to our one chief point of variance, namely, the cause of the arrest occurring in the flame movement, we are still unable to reconcile our results with his conclusions. Doctor Dixon suggests that we may find our difference to be mainly one of expression. We are, therefore, planning to submit a few of our photographs with detailed calculations of our results to him for consideration. By this means we hope to arrive at a true understanding of the phenomenon.

METHODS OF GEAR DESIGN AND GEAR-CUTTING

(*Concluded from page* 231)

be reached with a hob. So far as I know, all of the gears used on the Liberty engines were cut by the hobbing method. The gear that gets the real abuse in aviation is the gear between the engine and the propeller. Such gears were used to a limited extent, and the best results were obtained from herringbone gears cut by the hobbing process. The reason for this is that the herringbone or double helical gear is best suited for the job, and hobbing is best for the production of helical gears.

Automobile timing, turbine reduction and cream-separator gears would make better examples of applications under severe service. The turbine reduction-gears run at very high speeds carrying heavy loads and, if the tooth-form is not right, they will wear out very rapidly. The other two applications do not have the severe duty to perform, but the public demands that they run quietly, which calls for the same degree of care in cutting. Practically all of the automobile timing-gears in America are cut by the hobbing process. I have not checked up so carefully in other fields, but all of the turbine gears and cream-separator gears that I have come in contact with in recent years have been hobbed.

MOTOR-VEHICLE LEGISLATION

IN the 48 States there are no less than 17 different bases or combinations by which motor-vehicle license fees are fixed. For passenger cars the horsepower basis used by 27 States is the most prevalent while for motor trucks the commonest form is the rated carrying-capacity of the truck which is used in 25 States. Other bases are: Gross weight of vehicle and load, weight of vehicle, cost, piston displacement, total tire width, flat rate per vehicle and various combinations of the foregoing, as is brought out in Table 1.

TABLE 1—DIFFERENCES AMONG STATES IN BASIS OF DETERMINING MOTOR-VEHICLE LICENSE FEES

Basis of Determining License Fee	Number of States Using This Method for Passenger Cars	Motor Trucks
Horsepower	27	2
Carrying-capacity	0	25
Weight (vehicle only)	5	2
Gross Weight (vehicle and load)	3	7
Cost of Vehicle	2	1
Piston Displacement	1	0
Total Tire Width	0	1
Weight of Chassis	0	1
Flat Rate per Vehicle	3	2
Horsepower plus Gross Weight[1]	3	2
Horsepower plus Weight Unloaded	1	2
Horsepower plus Cost	1	0
Horsepower plus Capacity	0	1
Weight plus Cost	1	0
Weight plus Capacity	0	1
Weight plus Horsepower plus Cost	1	0
Weight plus Horsepower plus Cost plus Capacity	0	1
	48	48

[1]Basis recommended in uniform vehicle law.

In the case of a medium-priced automobile of about 25 hp., costing, say $1,700, the fees range from a minimum of $5 to a maximum of $34, while in the case of motor trucks far greater variations occur, the range being from $5 to $300 per year for a 5-ton truck. On the other hand, a flat-rate fee per vehicle, irrespective of weight or horsepower, is operative in three States for passenger automobiles and in two States for motor trucks. In only eight States is any reduction in the fee allowed for the use of pneumatic, instead of solid rubber, tires on motor trucks.

Gross-Weight Limitations

On the subject of the maximum gross-weight of the vehicle and the load combined that should be permitted on highways, State highway officials, motor-truck builders and users are far from agreement. The controversy is one of long standing and was one of the two main issues, the other being the measurement of tire width, on which the members of the joint committee on uniform vehicle laws failed to concur. As printed, the uniform law prescribes 28,000 lb. as the maximum gross-weight, but to this provision the highway members of the committee dissented. The question is an exceedingly complex one. Truck builders maintain, on the other hand, that lower transport costs are secured by the use of large truck units; highway engineers contend that the large heavily loaded vehicles are the chief agents of road destruction and that the apparent lower transport costs with the big units are actually nullified by the higher road maintenance and reconstruction charges that their use creates.

While it is not possible to quote any weight limit officially representing the consensus of opinion of State highway officials, it is believed that, except in those States where the main highways are largely of gravel or earth, the 5-ton truck is regarded as the heaviest unit for which, in the present state of the art, highways can be economically constructed and maintained. In Maryland, one of the States which have been exceedingly active both in the passage and in the enforcement of motor-vehicle laws, a gross-weight limit of 10 tons, roughly equivalent to a loaded truck of 5-ton carrying capacity is prescribed.

The extreme case of low maximum-limit is offered by Vermont, where existing laws limit the gross weight of a vehicle, except when special permits are issued, to 6¼ tons. In Colorado the maximum is 8 and in Maine 9 tons. Fifteen tons is the highest gross-weight limit prescribed, and is in force in California, Michigan and New Jersey. About 20 States place no restrictions on gross weight.

In addition to, or as a substitute for a maximum gross-weight specification, about half the States prescribe a maximum permissible loading per inch of tire width. This loading ranges from a minimum of 500 lb. in Idaho, Oregon and Texas, to 800 lb., the value recommended by the joint committee on uniform vehicle laws and adopted in a dozen or so States, including Connecticut, Illinois, Iowa, New Jersey, New York, Pennsylvania, Washington, Wisconsin, Minnesota, Massachusetts, Maine, Kentucky and Iowa. Table 2 summarizes the various weight restrictions in the State laws.

TABLE 2—SUMMARY OF WEIGHT RESTRICTIONS IN STATE LAWS

States	Gross Weight, Tons	Axle Load, Lb.	Weight Per Inch of Tire Width, Lb.	Wheel Load, Tons	Truck Capacity, Tons
Alabama	10	...	...	...	...
Arkansas	..	...	...	...	6
California	15	...	700	...	...
Colorado	8	...	...	...	...
Connecticut	..	...	800	...	...
Delaware	13	...	700	...	...
Idaho	..	...	500	...	...
Illinois	..	16,000	800	...	...
Indiana	..	...	...	...	7½
Iowa	14	...	800	4	...
Kentucky	..	...	800	...	...
Maine	9	...	800	...	...
Maryland	10	...	650	...	5
Massachusetts	14	...	800	...	...
Michigan	15	...	...	...	...
Minnesota	14	22,400	800	...	...
Nebraska	..	...	600	3½	...
New Hampshire	10	15,000	750	...	...
New Jersey	15	...	800	...	...
New York	12½	...	800	...	...
Ohio	10	14,000	650	...	...
Oregon	11	17,600	500	...	...
Pennsylvania	13	19,500	800	...	...
South Carolina	..	...	...	...	4
Texas	..	...	500	2½	...
Utah	11	...	600	3¾	...
Vermont	6¼	...	600	...	...
Virginia	12	...	700	...	...
Washington	12	22,400	800	...	...
West Virginia	11	17,000	600	4½	...
Wisconsin	12	18,000	800	...	...

Overloaded Trucks

The mere specification of a gross-weight limit is of little benefit unless some machinery is developed for its enforcement. In this respect many States are deficient. In others, such as Maryland, Connecticut, New Jersey and California, a real effort at enforcement is being made and both stationary roadside scales and traveling crews of inspectors with loadometers are employed to weigh at the roadside trucks suspected of exceeding the legal limit. Trucks loaded beyond their rated capacities are recognized by both highway engineers and motor-vehicle builders as a menace to highway transport development.

In some of the States where maximum gross-weights are specified the State highway commissioner or other official, as

TABLE 3—PRODUCTION OF MOTOR TRUCKS IN 1920

Capacity, Tons	Number	Per Cent of Total
¾	61,187	19
1	164,240	51
1½	35,424	11
2	25,763	8
2½	12,871	4
3½	12,893	4
5	6,441	2
Over 5	3,220	1
Total	322,039	100

is the case in Ohio, New Hampshire and elsewhere, is given authority to lower the weight limit at certain periods of the year when the frost is leaving the ground and the roads are soft. Without seasonal restrictions of this kind many miles of unsurfaced road would be rendered unfit for use in a comparatively short time if even a few trucks of great weight were allowed to operate over them during the spring thaw.

As will be noted from Table 3 the 1-ton truck is the prevalent size constituting 51 per cent of the 1920 production; the 5-ton truck constitutes only 2 per cent of the total output; and trucks exceeding a capacity of 5 tons represent only 1 per cent.

In a few of the States that have gross-weight limitations for motor trucks, exceptions are made in the case of trucks operating exclusively within city limits.

In addition some States place a tax on gasoline.

Future Changes Probable

State legislation governing the taxation and licensing of motor vehicles will undoubtedly undergo many changes in the next few years. The important thing now is for highway engineers and motor-vehicle representatives to work together to the end that future changes in State laws shall be just and lead to the best development of highway transport on economic lines.—From an article by R. K. Tomlin, Jr., in *Engineering News-Record.*

SEPTEMBER COUNCIL MEETING

THE meeting of the Council held on Sept. 15 was attended by President Beecroft, Past-President Vincent, First Vice-President Horning, Vice-Presidents Bachman, Crane and VanBlerck, Councilor Germane and Treasurer Whittelsey. There were also present, by invitation of the Council, V. E. Clark, C. F. Scott, C. B. Segner, L. R. Smith and F. E. Watts.

A financial budget for the current fiscal year, beginning Oct. 1, 1921, was adopted. This is based on a conservative estimate of the income of the Society for the year, the figure being slightly less than the income of last fiscal year which was somewhat in excess of $240,000. It is not the intention to curtail any of the activities of the Society that are considered of prime importance, and if necessary surplus funds of the Society will be used to defray expense of work recently inaugurated, such as that of the Research Department.

The balance sheet as of Aug. 31 showed that the net unexpended income for 11 months of the fiscal year ended Sept. 30, 1921, was $10,582.66. The income for the period was $224,875.39. The total assets of the Society were $169,151.17, these comprising general reserve of $140,641.18, which is the unexpended income accumulated in the last 10 years, and special reserves for distribution to income and expense items over the present fiscal year of $23,489.81, the accounts payable amounting to $5,020.18.

One hundred and ten applications for individual membership and two for student enrollment were approved, as well as the following transfers in grade of membership: Junior to Associate, Fred M. Brandmeier, Albert P. Lindenthal, E. J. B. Gorman; Associate to Member, Frederick L. Ortla, Warren Packard, A. M. Yocom, Carl A. Johnson, Gustaf Peterson, Irvin Fogg Richardson; Junior to Member, J. R. Bayston, H. C. Herbert, Charles LaPorte, R. S. Pfeiffer, C. E. Barton, Max L. Hillmer, Vincent Keenan, Charles H. Landon, C. A. Michel, Sherod S. Noe, George C. Rauhauser, R. H. Sanders, C. W. Sanderson, E. P. Warner, H. P. Wollensak, W. H. Worthington, Shin Matsu Yokoyama; Member to Service Member, R. S. Barnaby, Frank Walker Caldwell, Norbert Carolin, John Futhey Fox, David Gregg, Henry W. Harms, Floyd C. Hecox, James H. Herr, Robert F. Kohr, G. W. Lewis, Roy G. Miller, Thomas DeWitt Milling, Alfred S. Niles, Jr., A. Owen Seaman, Carel T. Torreson, A. V. Verville, Selden T. Williams W. Irving Chambers, F. Y. Dawson, Ernest J. Loring, William Henry Petit, Fred A. Truesdell, John J. Tucker, Gustav Wade, Herbert L. Wilson; Junior to Foreign Member, C. H. Dyke; Foreign Member to Member, G. W. Gaidzik, Frank C. Trachsel; Member to Foreign Member, George H. Bechtel; Junior to Service Member, E. V. Schaal.

Five hundred and forty-nine applications for membership were received in the first eight months of this calendar year, as compared with 948 for the corresponding months of 1920. On Aug. 31 there were 5590 names on the rolls of the Society, including affiliate member representatives and enrolled students, the corresponding figure for 1920 having been 4779.

The programs of coming meetings of the Society were considered with the result set forth in the first article of this issue of THE JOURNAL. It was understood, after much discussion, that in connection with technical sessions in conference with representatives of the oil industry, the spokesman of the Society who might be on hand should make a strong plea for the production over an adequately long period of a gasoline of definite known characteristics. It is felt that such uniformity and consistency are absolutely necessary in connection with the design, production and satisfactory operation of automotive apparatus.

The following appointments to the Standards Committee were made, with assignments as indicated:

C. E. Wilson—Electrical Equipment Division
J. M. Watson—Iron and Steel Division
Dr. F. C. Langenberg—Iron and Steel Division
A. M. Dean—Passenger Car Division
A. E. Garrels—Passenger-Car Body Division

The following subjects were assigned to Divisions:

Engine Torque—Electrical Equipment Division
Wire Meshes—Parts and Fittings Division

W. S. Haggott was appointed a representative of the Society on the American Engineering Standards Committee's Sectional Committee on Insulated Wires and Cables.

The Special Committee on Tire and Rim Standardization, of which Past-President Vincent has been serving as chairman, reported on matters relating to policy so far as cooperation of the Society with the National Automobile Chamber of Commerce and the Rubber Association of America is concerned. The committee was given the status of a Division of the Standards Committee and it is expected that its report in the matter of tire sizes recommended for use on future designs of vehicles will be submitted for approval at the meeting in January.

Discussion of Papers at the Semi-Annual Meeting

THE discussion of the papers presented at the recent Semi-Annual Meeting of the Society included written contributions submitted by members who were unable to be present and the remarks made at the meeting. In every case an effort has been made to have the authors of the several papers reply to the discussion, both oral and written, and their contents are included in the following discussions. The only exception to this is the paper by C. A. French entitled Flame, which was printed, together with the discussion thereon, in the August issue. A brief abstract of each paper precedes the respective discussion, with a reference to the issue of THE JOURNAL in which the paper appeared, for the convenience of members who desire to refer to the complete text as originally printed and the illustrations which appeared in connection therewith.

AIR TRANSPORTATION AND THE BUSINESS MAN

BY V. E. CLARK

IN his treatment of the subject the author purposes to assist in balancing the scale of public opinion and to clarify and guide the expectations and efforts of those who are associated in the development of the aircraft industry, hoping to curb the unrestricted enthusiast, encourage the disheartened aviation devotee and arouse at least a tolerant interest among progressive business-men.

Business uses for aircraft are suggested and commented upon at some length, the impediments to commercial air-transport are stated and a safe and reliable airplane service is outlined in some detail. Three requirements for landing fields are specified and considered in connection with navigation aids and landing in thick weather. The financial aspects of aviation, Government aid and the air mail-service are discussed rather specifically. [Printed in the June, 1921, issue of THE JOURNAL]

THE NEED FOR FEDERAL CONTROL IN COMMERCIAL AVIATION

BY S. H. PHILBIN

CERTAIN fundamental legal principles applicable to aviation are first discussed with special reference to National, State and private rights, although no attempt is made to cover them in detail. Following a comprehensive statement of the importance of commercial aviation, the author excludes military aviation as being beyond the scope of the paper and describes the present situation with regard to commercial aviation in the United States.

Aircraft inspection and examination, landing-fields, air-routes and rules of the air are treated in turn and special reference is made to an aeronautical safety-code as being highly desirable. The character of a suitable administrative body is outlined, seven specific desirable definitions of its authority being given. In conclusion, the statement is made that there is urgent necessity today for a carefully formulated and well administered plan of Federal legislation that will care for the immediate and future requirements of the aviation industry. [Printed in the August, 1921, issue of THE JOURNAL]

THE DISCUSSION

CHAIRMAN J. G. VINCENT:—It is interesting to me to note that Mr. Clark and Mr. Philbin, writing on different subjects from different points of view, arrive at exactly the same conclusion as regards the desirability of proper control. It is absolutely necessary to have control.

A MEMBER:—It was not until after the automobile really had become a commercial success that we began having good roads; perhaps we must get airplanes into service before we can hope to get municipal support for landing-fields.

CHAIRMAN VINCENT:—That is a good point, but probably the two must come together more closely than the automobile and the roads did. The automobile could get along on a poor road; it was more a matter of discomfort than of inability to get there. I believe that there is a movement all over the country toward landing-fields.

I think there is nothing that will interest the cities in voting landing fields so much as the air mail. A municipality will make great inducements to have the air mail routed to its locality.

F. E. MOSKOVICS:—I wish to challenge Mr. Clark's point of view. I believe that he has not touched upon what seems to me the most important factor of the present state of the art. If we study the business hisory of the world, we find invariably that the country that has the best means of transportation leads in culture, intellectual progress and development, and is invariably the material leader of the world. I shall not review ancient and modern history, but it shows clearly that the intellectual advancement and the culture of a country are in a direct ratio to the rapidity with which transportation can be accomplished between two points. In other words, the rapidity of interchange of thoughts and commodities and people goes hand in hand with progress. No one will argue against the fact that, within certain limits, the airplane is a practical and safe means of transportation. It seems to me that we must inspire men with the thought that, if they will come into this great enterprise, possibly without the chance of making money immediately, they will do about as patriotic and as great a thing for their own Country and for humanity as is possible.

About 18 months ago I received a telephone message at

noon from the commanding officer at McCook Field, 116 miles distant, that it was important for me to see some papers that were to be sent to Washington at 5:00 p. m. that day. I had to leave on a train at 4:00 p. m. for San Francisco. Capt. T. H. Bane said he would send the papers over within an hour by airplane. While I was at lunch a telephone message came that Mr. Clark and Major Schroeder had flown that 116 miles in about 40 min. The sun was not visible at any time during the flight and a sleet storm began before the day was over, but they returned to McCook Field. I could not possibly have seen those papers except for airplane transportation. Can anyone believe that the world does not want that kind of transportation? If not, it is the first time in history that a fleeter means of communication did not supersede a slower.

It seems to me that we should establish what might be called a bureau of propaganda to blazon the truth. The people and promoters who have the attitude of untruth in their statements are doing the greatest injury to aeronautics today. To promote a company simply to provide airplane travel for short distances where rail transportation is easy, is absurd. I think there is more activity on the Pacific Coast in the way of flying than in any other part of the United States. The fastest railroad train between Seattle and San Francisco makes the run in about 32 hr. The slow schedule is due to two mountain ranges and other natural barriers. The distance is about 800 miles in an air-line and the weather is fine during practically all of the year. An airplane today can make that flight easily in either direction in 8 to 9 hr. The forest airplane patrols work practically every day. The rainstorms are pretty much localized and the pilots navigate around and over them. Landing fields are already established practically 100 miles apart. A man drawing a $25,000 annual salary can afford to spend $200 for that trip, and an airplane that could carry five men at $200 each for the trip could make a profit.

CHAIRMAN VINCENT:—As Mr. Moskovics indicates, the airplane can be made a commercial success first as a means of transportation in those localities and under conditions where the present transportation facilities are not good, either by reason of the lack of railroads or steamship lines or because of the circuitous route that may be required. It is possible to find opportunities of that kind in the United States, and it is very important to bear this in mind.

W. E. WILLIAMS:—The steel passenger-car was put into use on the railroads of this country at a tremendous expense just to eliminate the thought of being burned up in a railroad accident. We have not appreciated fully the necessity of eliminating the danger of airplane fires. If we can construct the machines so that they will not burn up even though they fall, we will have made a greater stride to command public favor than can be accomplished by any other one line of improvement.

CHAIRMAN VINCENT:—There are plenty of engineers who know how to build airplanes that cannot be set afire.

S. H. PHILBIN:—We do have fire accidents now and then, but they are almost exclusively in the Government service. The public does not know what causes those fires or that the fire hazard is not equally existent in commercial airplanes. There is always a fire hazard wherever kerosene or gasoline is used, in a kitchen or in an airplane. The public must be told the truth about aviation. There are two practical ways of accomplishing this. Aviation is not yet full grown. We know that it will develop and that all the difficulties will be swept away when there is a public demand and we have quantity production, as was true of the automobile industry.

V. E. CLARK:—The fire risk is not a thing that the flyer fears much. For every thought he gives to fire he gives a thousand thoughts to the danger when he is getting into or out of a small field. Of course, a fire can be induced in an airplane, the same as in an automobile. Gasoline connections can be bad enough that grave danger of fire results, or gasoline tanks can be located and arranged so that fire will result in case of a crash.

CAPT. H. E. HARTNEY:—The solution of commercial aviation is not so far distant as one might be led to believe. Comparatively speaking, it is held up by only a few minor problems at present.

There is not one single commercial airplane operating in this country at present. If every airplane we have were destroyed and replaced by an uptodate commercial machine, commercial aviation would be established on a sound basis within two years. The by-products of flying, mainly the fruits of the operations of the aerial camera, would go a long way toward paying the overhead of the operating companies and leave a good margin for transportation of cargo and passengers.

It is not sufficient that cities and towns have landing fields; they must be linked into a well-organized system of airways. Belts of emergency and auxiliary landing-fields corresponding to highways and railroads must be established so that airplanes traversing the Country will follow routes just as steamers follow certain lanes across the ocean. The permanent establishment of municipal landing-fields throughout the country is in itself an impediment to aerial transportation. The sooner those interested in aeronautics make a bid for airways rather than unrelated landing-fields, the sooner the docking requirements of airships and airplanes will be solved and regular air-transportation schedules become operative.

REQUIREMENTS OF AERONAUTIC POWERPLANT DEVELOPMENT

BY G. J. MEAD AND L. E. PIERCE

IN discussing the probable trend of aeronautical powerplant development and subsequent to a brief survey of the present situation, the authors review the evolution of various engine types and analyze the effect of their characteristics on airplane performance, considering also the proper installation of airplane powerplants. The problem now confronting the industry is one of establishing standard types for the powerplants required by each service and setting up reasonable power requirements for each unit. For each service, factors must be developed to permit the making of correct comparisons of the performance of the different engines.

The future types of engine are considered at some length and special reference is made to radial engines. Curves and tabular data accompany the discussion of variations in engine elements and the characteristics of a high-speed airplane are treated in a similar manner.

Following a lengthy review of the factors that should govern powerplant installation, a summary of the paper is presented in conclusion. [Printed in the July issue of THE JOURNAL]

THE DISCUSSION

E. A. SPERRY:—One of the enemies of aviation is the fire risk. Many aerial accidents have been caused by this within the past two years, and the horrible part is that so many of our fine pilots have actually been burned to death. The airplane always vibrates more or less and there are always nodes in those vibrations; some joint in the gasoline system will spring a leak and fire has in many cases occurred from the exhaust or from the electric ignition system. Almost invariably a fire will occur following a smash-up. The aviators often would have time to extricate themselves were they not confronted with a sheet of flame that not only smothers the pilot but envelops hundreds of square feet all around him. In such instances the pilot is asphyxiated immediately.

Some believe that we ought to run aircraft on nothing short of some kind of fire-extinguishing fluid; that we ought to use something that will not burn, heavy bunker oil, used under the boilers on ships; not Diesel-engine oil, which costs about the same as kerosene, but bunker oil. When some of it is evaporated to dryness, as high as 21 per cent of solids remains in the bottom of the flask, but it passes through the Diesel-engine cycle perfectly clean; its exhaust is odorless and colorless; it has 25 per cent more British thermal units than aviation gasoline, and much less is used for a given power. That oil is a fire extinguisher.

Because of a circular that came to me not long ago, I sent for samples of a trade compounded metal. Take, for instance, metals heavily alloyed with magnesium. I found some that have a 60,000-lb. tensile strength, but there is an admitted trouble in that the shavings are very inflammable and might catch fire under a lathe, for example. We were told not to use water on those shavings if they caught fire. In Frankfort, which has the largest factory that handles this material, their practice is to have a pail of fuel oil available; they dash the oil on the metal shavings in case of fire and it immediately extinguishes the flames.

There seems to be no ordinary way to set this fuel on fire. McCook Field has tried it with every kind of incendiary bullet, even those magnesium bullets that will set the most non-inflammable gasoline-tank on fire. It is impossible to do any such thing with that oil; in one instance it was made to smoke when a thick rag was saturated with it. The rag was hung up and a number of incendiary bullets put through it; but that was the nearest approach to a conflagration that we could get. Of course, gasoline will spring into flame instantly.

If we could use the Diesel cycle, we would accomplish many things all at once. We could eliminate the fire risk, use a considerably smaller percentage of fuel, get a very much higher thermal efficiency and a gallon would carry us much farther. The trouble with the Diesel engine is that it has been so tremendously heavy up to the present. It seems almost impossible, but we have found what appears to be a way out of the difficulty. We have obtained now about 3000 hr. of operation of the machine; I think our series of cards consists of more than 2700. The construction has gone through many changes, the principle is established and we have thrashed out many of the necessary refinements. The Diesel engine has been described as a mountain of cast iron with a little driblet of power issuing at one end. This is very well illustrated by the fact that the standard Diesel engines of today weigh from 250 to 500 lb. per b.hp.

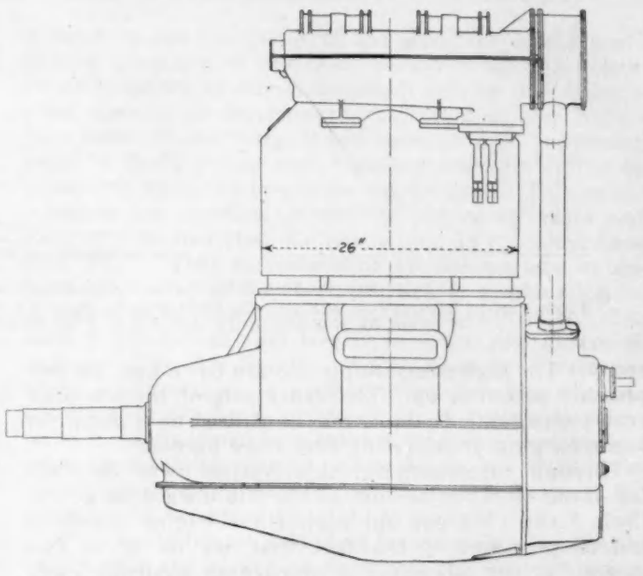

FIG. 1—ONE UNIT OF AN AVIATION ENGINE USING AUTO-IGNITION AND HEAVY FUEL-OIL

Fig. 1 shows our development of one unit of an aviation engine using auto-ignition and heavy fuel-oil. This engine consists of two high-pressure cylinders separated by a low-pressure cylinder. It is built about as small as we dare to build a Diesel engine; that is, 5 x 7 in. As compared with a two-cylinder Diesel, simply by separating those two high-pressure cylinders and putting a low-pressure cylinder between, we get in this engine about six times the power. This engine has 6 to 1 high and low-pressure cylinder compression ratios. The first engine, without many refinements still to come, works under 5 lb. per hp., which represents a large gain in power for a given weight.

Fig. 2 shows a working drawing of a 10 to 1 compound engine, showing the internal arrangement. The crankshaft is sturdy. The two outer cranks are down. The low-pressure crank is in the center and is shown in the up position; the engine is thus balanced very per-

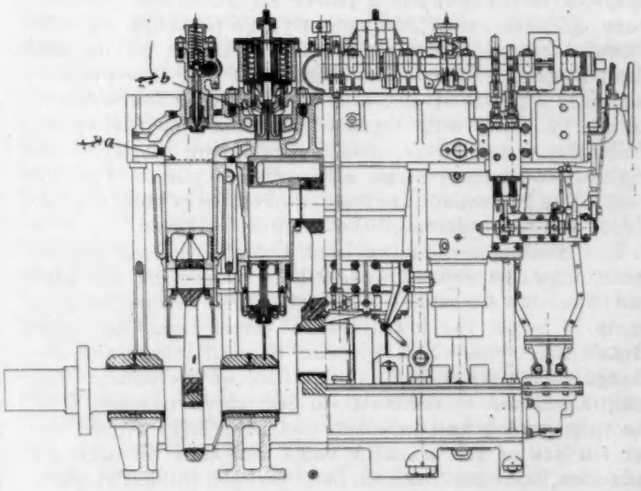

FIG. 2—WORKING DRAWING, PARTLY IN SECTION, OF A 10 TO 1 COMPOUND ENGINE

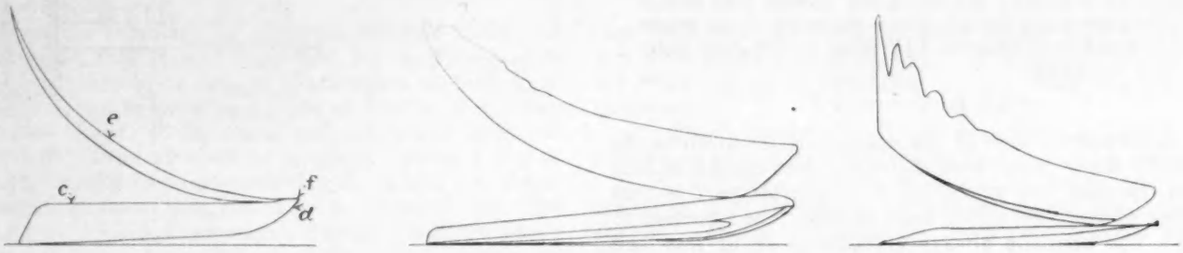

FIG. 3—THREE INDICATOR CARDS OBTAINED FROM THE ENGINE SHOWN IN FIG. 2
From Left to Right These Are a Cyclic Card without Fuel, a Card Showing the Range of Control from 10 Per Cent Overload to Idling by Regulating the Amount of Fuel Injected and a Card Showing a Straight Detonation

fectly. The high-pressure pistons are down and the low-pressure piston is up. The under side of the low-pressure piston, outside the trunk, is utilized as a pump for supercharging or delivering first-stage pure-air.

Through supercharging, this Nation owns the ceiling of the world on account of the fine work done at McCook Field. We get our high Diesel-engine pressures and temperatures by the fact that we do it in two stages. If one attempted to procure an air-pump capable of developing a pressure of 515 lb. per sq. in., the manufacturer would never think of making a pump to do this in one stage, but would ask how many stages were wanted. Fig. 2 shows a two-stage compression which gives wonderfully good results.

The trouble with the Diesel engine is that it has only a very slight amount of oxygen to work upon at high pressures, and that amount for only an instant. This makes it very heavy in comparison with its power. The clearance space is about one-twentieth of the piston displacement, and that indicates the total amount of oxygen that a Diesel has available. That is the disadvantage of its weight; it is designed around a very small amount of oxygen shown under the dotted line *A*, whereas, in the compound, we have a very large amount of oxygen to work with because of the very large dome representing the clearance or combustion-space above the high-pressure piston. Having such a large amount of clearance, we are enabled to supply both high-pressure pistons and then go right over to the low-pressure piston and follow it to the end of its stroke with pressures still above that of the atmosphere. The two high-pressure cylinders are four-cycle, one being 360 deg. behind the other, so that a power stroke in one high-pressure cylinder is followed by a power stroke in the low-pressure cylinder; then the other high-pressure cylinder likewise supplies the low-pressure cylinder on its next down-stroke. Every down-stroke of the low-pressure piston is a power stroke, and we get a true four-cylinder action by using only three cranks and two fuel-valves. Solid fuel-injection is used, eliminating entirely the high-pressure three-stage air-injection pumps for the fuel. The fuel-valves are located over the center of gravity of the large dome of the combustion-space.

The combined induction and transfer valves are directly over the short transfer port connecting the high and the low-pressure cylinders. The supercharging pump is below the low-pressure piston-head and surrounds the trunk. Semi-circular rows of intake and discharge valves are in the annular floor of the pump. The compressed air is delivered to the cored passage *b* in the valve casing and intensely cools the large ribbed upper surface of the transfer valve and stem on each air induction, washing these surfaces on each induction quarter of the four-stroke cycle, which immediately follows the transfer or heating period. The charges to the low-pressure cylinder alternate from the two high-pressure cylinders, as stated.

At the left of Fig. 3 is a tracing of the cyclic card of the compound without fuel. This shows the first stage of compression from the pump driving the piston during the induction stroke *C*, the mean effective pressure being considerably greater than in the standard Diesel; it is about 111 lb. per sq. in. in the engine having the 10 to 1 ratio. The induction valve closes at *d* and the compression proper starts from this stage and attains 515 lb. per sq. in. on the line *e*. Receiving no fuel, it comes down on nearly the same line and passes through the transfer valve *f* into the low-pressure cylinder and down below the atmospheric line somewhat before the exhaust-valve opens. The exhaust is refrigerated in a cold engine when no fuel is supplied and stands at 6 to 10 deg. cent. (42.8 to 50 deg. fahr.).

This engine is controlled by regulating the amount of fuel injected. The card reproduced in the center of Fig. 3 is from a 10 to 1-ratio compound, showing the whole range of control from 10 per cent overload to idling. From the top of the compression curve to the left, the horizontal line of combustion indicates the ordinary slow Diesel burning. In the Diesel cycle employed in the compound, a constant quantity of air is always compressed and just enough fuel is added at the upper dead-center to do the work. Combustion is always complete and the efficiency is very high.

The view at the right of Fig. 3 shows something contrary to the general theory that to get a quick rise of pressure it is necessary to anticipate the fuel-induction point and put the fuel in with a considerable lead. The compression-line proper has here gone to its peak to the left and started back before the fuel induction has taken place, showing that a quick rise of pressure has nothing whatever to do with the timing of the fuel injection. This has to do with another matter also, in that instead of having the expansion ratio of ordinary automobile engines, from 4 to 1 as compared with the Diesel's 12 to 1, we are enabled here to get an expansion ratio of 120 to 1, and make a very great gain. We have been able to couple up supercharging with super-expansion and yet retain very low weights.

It will be recognized that the card at the right of Fig. 3 is a straight detonation card, but it gives a very good idea of just how the cycle works throughout. It cost much time and money to accomplish it, but we have found how to detonate almost any fuel. We can take doctored fuel that is guaranteed against detonation and detonate it with perfect ease in this cycle. While automobile engineers have been trying to dodge detonation, we have been trying to harness it and put it into service. It is very useful because it piles up the heat as far from the exhaust-valve as possible. In a Vickers engine we have only about 95 deg. of crankage available be-

tween the time of the cut-off of the fuel and the opening of the exhaust-valve. But, by detonation, we pile the heat just as far away from the exhaust-valve as possible, and we have to go some 310 deg. before the exhaust-valve opens. So, we conserve the power gases. The consequence is that we are able to turn a larger percentage of the exhaust gases into useful effort on the crank and the exhaust is cool, just as it should be. Instead of the 60 to 70 lb. per sq. in. net mean effective pressure to the crank of the Diesel, with the compound we are enabled to get from 600 to 700 under conditions of very much better distribution than in the Diesel, namely, two strokes that succeed each other, each having half of these effective pressures reduced to the ordinary standard, that of the combustion cylinder area.

R. W. A. BREWER:—So long as the subject of fuel and its preparation for use in the engine is relegated to the background, so long shall we be faced with the fire risk. In view of the very high state of development to which the modern automobile engine has been carried, we ought to benefit by this development as an engine proposition and turn a certain amount of attention to the use of fuel which does not carry with it this fire risk. There are two lines of development to which attention is called. One is that when carrying on demonstration for some Roumanian chemists on what was called solidified gasoline, about 10 years ago, it appeared to be a most suitable fuel for aeronautic purposes because it actually was gasoline formed into a jelly. This jelly contained only about 0.5 per cent of foreign substances, which did not in any way impair or interfere with the combustion of the fuel, because it was precipitated out after the fuel had gone through the tank. The fuel was absolutely safe because there was no spillage and a piece of it lighted with a match would burn like a candle. The only way of using it was under a small pressure that squeezed it out as liquid squeezes out from a sponge.

To prepare the fuel, ordinary gasoline received a temperature treatment, some stearic acid and wax were added and a kind of suds was formed, which was allowed to cool, the operation only taking about 30 min. This emulsion, in its solidified form, was cut into cubes of any convenient size and put into the tank. That is all there is to it. In the tank the vapor was utilized in the ordinary way. The only amount of inflammable vapor in the whole system was what was contained in the pipe that led from the tank to the engine. That seems to me a very simple sort of solution of this fire-risk problem.

Alternatively, there is the use of a fuel which is non-explosive at ordinary temperatures and under usual conditions. Much attention has been drawn lately to the methods of preparing such a fuel for use in an internal-combustion engine, because gas is what drives the engine, not liquid. If we consider the modern engine a gas engine, we can now almost wipe out the loss of volumetric efficiency that we know is occasioned in feeding an engine with gases, distinct from liquid, by reason of the supercharging devices, or forced induction systems, that have come very much to the fore lately. An aviation engine is a gas engine and, if it is treated as such, we shall surmount many of the difficulties, particularly those due to fire risk.

MR. WILLIAMS:—Mr. Sperry has described possibilities that should be studied very seriously, not only for the aviation field but all fields where the internal-combustion engine is used.

CHAIRMAN VINCENT:—Messrs. Mead and Pierce have compiled in one paper much valuable information which is more or less the result of the activities of the engineering divisions of the Air Service and the Navy. Those branches of our Government service are doing a great amount of development work that is very valuable. Some of the work is not necessarily of particular value in itself, but in such instances they are trying to determine what things should *not* be done. This paper refers to the practical number of engine cylinders and mentions the fact that engines having 18 cylinders have been made. That is being done for the purpose of determining what is the most practicable combination of cylinders. Only the Government can do such work. The same thing applies very largely to radial and air-cooled engines. The Air Service officials know that such engines are practical in certain sizes, but they do not know where the limit is and they are trying to determine it. This paper is important as giving a résumé of what the situation seems to be to date. The work is being continued and, naturally, development will change the situation from time to time; it has many angles.

NEIL MACCOULL:—What fuel economy does Mr. Sperry obtain with the engine he describes and what maximum speed has he secured so far?

MR. SPERRY:—We approach 0.42 lb. per b.hp.-hr. in rather a crude construction. We know much more now than we knew six years ago when the engine was designed. As to speed, we seem to have no limit, especially with regard to the performance within the cylinder. An engine of this type has run 1600 r.p.m.

C. E. SARGENT:—In connection with Mr. Sperry's description of this new Diesel cycle, it occurs to me that the same economy can be obtained with the single expansion engine as with the compound, especially in gas-engine practice. We compound a steam engine on account of the cylinder condensation. We do not have this to contend with in gas engines. Experience with stationary engines shows that expansion to atmospheric pressure gives the same economy that is obtained in a Diesel engine, even with low compression. Mr. Sperry has given us a wonderful start toward fuel economy, for aeronautic, automobile and tractor engines, which we must meet very soon if we expect to maintain the automotive industry.

MR. SPERRY:—Our view of this compounding of the steam engine is exactly the reverse of Mr. Sargent's. We believe that condensation is the greatest enemy to compounding. Because of the fact that we have no such thing as condensation in the internal-combustion engine, we will have a much richer reward than was ever possible in steam compounding. In reciprocating steam-engines compounding stops at about 15 to 1 to 18 to 1. Here is an engine that already has run about 120 to 1. We gain more by compounding an internal-combustion engine than by compounding a steam engine because we have a very much greater range of pressure at our command. The American Society of Mechanical Engineers appointed a committee last winter to see whether boiler pressures could not be increased to provide more pressure for compounding. Here we have already in hand a pressure of 1000 lb. per sq. in.

Although we hear much about the safety of aircraft against fire through the ignition of gasoline, the constant recurrence of the burning of planes and the loss of life through fire, especially at the time of smash-up, emphasize the importance of eliminating the fire risk.

MR. BREWER:—The subject of the compound gas engine was threshed out years ago. Owing to the low specific heat of the exhaust gas of a gas engine, there is absolutely no object or advantage that can possibly be ob-

tained from a further expansion of exhaust gas in a separate cylinder in a gas engine. The waste heat from the exhaust of a gas engine is of practically no value except for ordinary heating.

A. D. T. LIBBY:—Discounting the reliability aspect of the ignition, what has been found regarding increase of power in the use of two, three or four-spark ignition on these multi-cylinder engines?

CHAIRMAN VINCENT:—I am now conducting experimental work on a large six-cylinder engine which is very much like the engine that is described in the Mead and Pierce paper for dirigible work. This engine has 6⅝ x 7½-in. cylinders and is a four-valve type. As pointed out in the paper, for dirigible work fuel economy is of much more importance that low weight; naturally, no unnecessary weight is added. The engine has just completed a 50-hr. test. Knowing that detonation would be one of the chief troubles in that engine, we provided four spark-plugs, spaced as nearly equally around each cylinder as possible without having the spark-plugs in adjacent cylinders dangerously near to each other. We found that with the four spark-plugs in good condition and with proper ignition, detonation was reduced very materially. We found, however, that we could not go above 5 to 1 compression-ratio without severe detonation. During the 50-hr. test, which was run with a 5 to 1 compression-ratio, there was a slight detonation at times. It seemed to occur in cylinders Nos. 2 and 5 more frequently than in the other cylinders and, was, I believe, due to poor gas distribution. We tried a 5½ to 1 compression-ratio with the four spark-plugs and could not operate the engine without using benzol. It was very interesting to cut-out just one of the spark-plugs; the engine would detonate terribly. In my opinion, it is absolutely necessary to have at least four spark-plugs in a large engine of this type, unless one can be placed in the middle of the cylinder-head or some other arrangement made that we did not find possible. The engine seemed to act just about as badly on three as on two spark-plugs, due, no doubt, to the way the spark-plugs were arranged. The cylinders were very well cooled.

MR. LIBBY:—Did the detonation you describe occur at any particular speed?

CHAIRMAN VINCENT:—The engine was running constantly at a speed of 1400 r.p.m.

A MEMBER:—What is the principal deterrent in this country to the development of the stationary-cylinder radial water-cooled engine? Why has it not been developed as much in this country as in Europe?

L. E. PIERCE:—We are starting the development of the stationary-cylinder radial air-cooled engine; it is still in the experimental stage. I think the water-cooled engine will come second if the air-cooled engine develops successfully. I believe that the radial engine of high horsepower will not be very adaptable in aircraft development.

CHAIRMAN VINCENT:—The air-cooled engine is made radial because of the necessity of such construction for cooling purposes rather than that the arrangement is particularly desirable from an airplane point of view.

I think that the danger from fire hazard has been exaggerated. It is necessary to have a good engine to design an airplane, and necessary for the airplane designer to know something about how that engine should be installed. With our present knowledge we can design for an airplane a really reliable powerplant installation, or installations, as the case may be; and it is possible to build an airplane that cannot catch fire except through gross carelessness, machine-gun fire or the like. When flying an airplane, I have no more fear that it will catch fire than I have that an automobile will catch fire when driving it. With a modern airplane engine, properly installed, there is absolutely no danger from fire. Where the engineer really has a chance to do a good job, he installs the engine so that it cannot cause fire, even if the fuel pipes break.

L. M. GRIFFITH:—The statement that "the power required to overcome the inertia of the reciprocating parts increases rapidly with the increase in the cylinder bore at a given speed," is evidently incomplete, inasmuch as the increase in power is not directly the result of the increased inertia but is due to the increase of friction resulting from the increased bearing load caused by the higher inertia forces. The authors undoubtedly appreciated this distinction, but it occurs to me that a clarification of the statement can do no harm. As a matter of fact, the friction losses in fully lubricated sliding bearings are dependent almost entirely upon the sliding velocity and the nature of the lubricant, any increase of the unit load having a negligible effect so long as the lubricating film is maintained. This indicates that the increase of shearing velocity in the oil-films at the several bearing surfaces is of much more effect in increasing the mechanical losses of the engine than is the increase of bearing load due to increased inertia forces.

It is noted that the authors' discussion of the rotary type of engine is limited to the single revolving-cylinder type, the double revolving engine not being mentioned. Nevertheless, the latter type has many important advantages for certain classes of service, inasmuch as the power output can be approximately doubled by this means, without any increase of the head resistance. The double revolving engine is readily operable at speeds of about 2500 r.p.m., the propeller being driven at one-half this speed without extra gearing.

No mention is made of the barrel-type engine, in which the cylinders lie parallel to and drive a simple shaft by one or two so-called swash-plates. This omission is important, as the barrel-type engine has many important advantages such as extreme compactness, relatively light weight, low head-resistance, mechanical simplicity, ease of installation, perfect mechanical and impulse balance and extreme accessibility. These characteristics make this type of special value for multiple-engined airplanes where the power units are mounted in nacelles or in the leading edges of thick wings. From the military standpoint the type is of decided interest due to the fact that gun-fire can be directed through its simple hollow shaft without necessitating a synchronizing gear.

The relation between engine weight and fuel economy does not appear to be expressed exactly correctly in the paper. If a reduction in the fuel consumption of 1 lb. per b.hp.-hr. necessitates an increased powerplant weight of 1 lb. per b.hp., the total mean weight of powerplant and fuel will be equal in the two cases for a flight of 20 hr. and not 10 hr. as stated.

S. D. HERON:—In view of the many broad statements at present finding utterance in this country regarding air-cooled aircraft engines, it seems that an investigation of the present state of knowledge is justified. Frankly, I am biased in favor of the air-cooled engine, but I am not so prejudiced as to be unable to grant that water-cooling has advantages, or to claim that air-cooling has reached the pitch of development of water-cooling. Positive statements regarding air-cooled engines are made in the paper to the effect that:

(1) The parasitic resistance of the air-cooled engine is

considerably higher than that of the water-cooled engine
(2) The reduced vulnerability of the air-cooled engine is of little practical military advantage
(3) Air-cooling at present allows of only relatively low mean effective pressures
(4) Air-cooling does not allow of easy temperature control
(5) The weight comparison of the two types is not favorable to the air-cooled engine

Little evidence regarding the relative resistance of air and water-cooled units seems to exist; if it does exist, it is by no means widely known. The only figures I have been able to obtain are that the engine and body resistance of an RE-8 machine with a 150-hp. RAF-4A engine, which is a 12-cylinder air-cooled V-type engine with a scoop cowl, is 53 lb. per sq. ft. and for an RE-8A machine with a 200-hp. Hispano engine, which is exactly the same as the RE-8 machine except for the engine, engine fairing and cooling system, it is 66 lb. per sq. ft. Both of these values are from a Royal Aircraft Factory report and are at 100 ft. per sec., and for tests on one-fifth-scale models.

It has been stated on good authority that model tests have shown that the resistance of an air-cooled radial engine is somewhat higher than that of a water-cooled 8-cylinder V-type engine but, on the other hand, full-scale tests on the Sopwith Snipe and Nieuport Nighthawk have shown a level flying speed of over 140 m.p.h. at a 10,000 ft. altitude, this performance in the case of the former being obtained with an engine that was not giving more than 280 hp. on the ground, and probably less, which seems to indicate that the resistance cannot be so much in excess of that of a water-cooled engine of similar power. Further, it can be pointed out that the ABC Dragonfly engine has relatively high resistance for the power given, and that an engine of similar size and resistance with high-efficiency cylinders could be built to give 400 b.hp. at sea level. It would be of considerable interest if Messrs. Mead and Pierce would produce figures and the authority for their statements regarding relative resistance.

In view of the fact that the air-cooled engine has a considerably higher mean-temperature difference between the cooling surfaces and cooling air than the water-cooled engine, between 220 and 280 deg. fahr. mean temperature above air being an average figure for an air-cooled cylinder running with a blast velocity giving maximum power, the mean temperature depending upon cylinder size and the blast velocity varying from about 60 m.p.h. for a 65-cu. in. cylinder to 85 m.p.h. for a 150-cu. in. cylinder, and will therefore require less air to dissipate a similar amount of heat, it seems that there is a fair expectation that the resistance will therefore not greatly exceed that of a water-cooled engine faired with equal skill.

The statement that

> Air-cooling has advantages for an airplane, due to the tremendous differences in temperature under which the engines are forced to operate. It also makes the engine somewhat less vulnerable when used for military purposes. This does not seem to be a very important feature, since most planes that are shot down apparently fall because of fire rather than any other cause

does not agree with the views of many pilots who flew on the Western Front during the war. Many cases are on record of machines being brought down by a single shot through the radiator or a water-jacket. For instance, the engine from which the first official British published data on the 160-hp. Mercedes engine were obtained, was put out of action by a single shot through a water-jacket. Further, the connection between shots through the cooling system and the falling of the airplane in flames seems somewhat remote. The British, who used the stationary air-cooled engine to a greater extent than other belligerents in the great war, had a great respect for this type of engine on the score of reduced vulnerability.

A cylinder of 5⅞-in. bore by 6-in. stroke and of American design and manufacture, at 29.9-in. barometer and a 60-deg. fahr, air temperature, has given 120 lb. per sq. in. brake mean effective pressure at 1800 r.p.m., this cylinder being as yet relatively undeveloped. In view of the fact that few water-cooled engines of such size greatly exceed the above mentioned performance at such speed, it appears that fairly high mean effective pressures are not only a matter of report.

There is much doubt as to whether any real difficulty exists with reference to temperature control, provided the supply of heat to the induction system is such as to maintain reasonably constant carburetion and distribution. It is my experience, not alone with the aircraft engine, but with air-cooled engines generally, that it is possible to operate over a range of as much as 350-deg. fahr. variation in maximum cylinder temperature without any relatively large variation in engine performance.

While I am doubtful of expressing views on the matter of weight comparisons, as insufficient experience is at hand to make any sound conclusion, it does not seem fair to compare air-cooled engines operating on normal fuel and compression-ratios and a special water-cooled engine using a compression-ratio in excess of 6 to 1 and doped fuel, and further leaving the weight of the water and the radiator out of account. I refer to the statement that

> The V-type eight-cylinder engine is undoubtedly the lightest water-cooled engine known, for the reason that it has the shortest crankshaft for a given power. Weight factors of 1.45 lb. per hp. have been secured from this type of engine.

Mr. Vincent's statement to the effect that the radial form of engine was adopted on account of cooling difficulties, is not borne out by investigation. One 12-cylinder air-cooled V-type engine giving 220 hp., produced by the British in 1917 and subjected to severe experimental tests on the dynamometer and in the air, cooled as satisfactorily as any radial engine I have yet seen and, incidentally, much better than most water-cooled engines of similar power. The main disadvantage of the air-cooled V-type engine lies in the necessarily greater length compared with that of the water-cooled unit, due to the space required between cylinders. Experience in Europe has shown that the large V-type engine with 40-hp. cylinders does not have insurmountable cooling difficulties.

Comparatively little work has been done on the 9-cylinder single-row 300 to 400-hp. air-cooled radial engine, as no really satisfactory engine of this type has been produced. The mechanical difficulties of such an engine are not easy of solution and will need much careful work before the standard of maintenance and reliability set by the best water-cooled line or V-type engine is equalled. An engine of such power will have an approximate minimum overall diameter of 48 in., and the question of cowling and fairing for minimum resistance with good cooling will call for careful design and investigation. When experience is obtained by airplane and powerplant designers and test staffs, a considerable im-

provement on present fairing methods will no doubt be obtained rapidly. The problem can hardly be said to have begun to exist, as large air-cooled radial engines have not been used other than experimentally in small numbers. By enclosing and streamlining the valve gear and springs as far as possible, it is probable that a considerable reduction in the head resistance can be obtained; up to the present this feature has had little or no attention.

In the light of present-day knowledge it seems that if the air-cooled engine for military work is to compete with the water-cooled engine in the 400-hp. class, the only hope lies in the high-efficiency cylinder developing a mean effective pressure in excess of 130 lb. per sq. in. and using high compression. Experience has shown that a high mean effective pressure is necessary owing to the fact that the successful air-cooled cylinder has proved to be fairly heavy on a basis of weight per cubic inch of volume swept to weight. To design a cylinder of 150-cu. in. swept volume with a weight of 0.65 lb. per b.hp. requires considerable finesse.

The use of high compression has been shown to improve air-cooled performance, not only as regards the power developed and the fuel consumption, but the cooling efficiency as well; and, in this connection, the use of fuel dopes allowing of compression-ratios in excess of 6 to 1 gives promise of further improvement. On single-cylinder test engines, brake mean effective pressures of 135 lb. per sq. in. have been maintained regularly, but this is with lower blast velocities than are obtained under almost any flying condition in a pursuit machine. Such performance has been secured only under favorable conditions that would not exist in a multi-cylinder engine under service conditions, but this is likely to be balanced by the improved fuels for high compression and the eradication of faults that are shown in the cylinders while giving the performance mentioned. High performance from air-cooled cylinders is not obtained from the first casual idea produced on the drawing-board, or in the first run on the test block, but is the product of long and exacting test and design work. Owing to the wide variation in climatic conditions existing between the Mexican border and Alaska, it appears that the air-cooled engine has many advantages for military use in this Country. It would be unfortunate if the possibilities of the air-cooled engine were left untried owing to an attitude of mind that condemns without investigation and because all the problems have not been solved already. What would be the present state of aviation had the pioneers thought along such lines?

CHAIRMAN VINCENT: — I believe Mr. Heron's objection to my statement that air-cooled engines are made in the radial forms for cooling reasons rather than because of aircraft requirements is not really justifiable in the light of practical experience to date. Mr. Heron refers to the RAF-4A air-cooled V-type engine as an example of what can be done in constructing air-cooled engines in other than the radial or rotary form. According to the best information in my possession the engine weighed 4.17 lb. per b.hp., had a fuel consumption of 0.68 lb. per b.hp-hr., and an oil consumption of 0.067 lb. per b.hp-hr. While these figures undoubtedly can be, and probably have been, improved upon in other engines of this type, the horsepower-weight ratio and the economy figures given, as compared with water-cooled engines, leave much to be desired.

I wish to go on record as being a firm believer in the future of the air-cooled aircraft engine for certain purposes, and it is my conviction that the radial type offers the best field for development. I see nothing in the V-type air-cooled engine to commend it except a reduction of resistance, which in itself is open to question. The air-cooled radial engine has advantages in ease of cooling and mounting, accessibility, compactness and possibilities of weight reduction, that, to my mind, would more than offset any increase in resistance as compared with the V-type air-cooled engine.

I think, now as always, that air-cooled aircraft engines will be used extensively in the future and that, of the radial, rotary and V-type engines so far constructed, the radial engine has overwhelming advantages and deserves the greatest encouragement in development.

G. J. MEAD:—It seems that Mr. Heron's principal criticism was that we had overlooked the fact that much better air-cooled engines could be built. Apparently he did not understand one of the premises of the paper, namely, that it dealt with the actual performance of existing engines. I entirely agree with Mr. Heron that there is a possibility of considerable development of this type of engine. I will take up the points in the order in which they were discussed by Mr. Heron, with the hope that our ideas on the subject of the air-cooled type of engine will be set forth more clearly.

The statements regarding the parasitic resistance were based upon a mathematical consideration of a 375-hp. radial engine approximately 50 in. in diameter. The values derived were stated in Table 1 of our paper, as compared with those of a water-cooled V-type engine of similar power. The conclusion drawn from the figures was that an airplane with the air-cooled engine would have a loss in high speed of some 5 per cent compared with the same airplane with a water-cooled design. As Mr. Heron says, there are available no figures based on actual performance, at least not to our knowledge. It seems reasonable to suppose, however, that an engine with such a large frontal area would require more power for its propulsion through the air at a corresponding speed than another engine of equal power with less frontal area in the same plane. Engines smaller in diameter, 40 in. or under, will not be subject to this criticism, since they fair into the fuselage very nicely.

On the subject of vulnerability, the consensus of opinion of some of the pilots who were on the Western front seemed to be that more planes come down because of being set on fire than because of injury being done to their cooling systems.

We stated in the paper that relatively low mean effective pressures had been secured up to that time in this Country, which was correct at that time, I believe. We were not discussing the probable mean effective pressures that could be secured. The mean effective pressure of 120 lb. mentioned by Mr. Heron, was secured only very recently with a single experimental cylinder, I understand.

It is a more difficult problem mechanically to control the temperature of an air-cooled engine than of a water-cooled engine. This, I believe, will be granted. Whether it is necessary to provide temperature control, has yet to be proved.

Attention was drawn to the fact that, so far, air-cooled engines weigh very nearly the same per horsepower as the best water-cooled engines, complete with the water and the radiator. Mr. Heron makes the statement that successful air-cooled cylinders have proved to be fairly heavy. For that reason, it is necessary to increase the mean effective pressure to make these engines capable of competing with water-cooled engines in the 400-hp. class.

In conclusion, the whole radial air-cooled situation, as

I see it, is that the question whether large radial air-cooled engines are to supplant or compete with water-cooled engines, depends first upon developing cylinder constructions that will permit high mean effective pressures, and also the development of the mechanical parts of the engine so that they will be sufficiently durable for the service expected of them. I see no reason why air-cooled cylinders will not be developed that will give high mean effective pressures. Naturally, there is much careful experimental work to be done before the maximum efficiency of this type of cylinder can be obtained. Mr. Heron is doing some very conscientious work on this problem, and undoubtedly will be able to tell us in the near future of the cylinder limitations. In the meantime, development work must be carried on with the mechanical parts of the engine, including the crankcase, crankshaft, connecting-rods and valve-gear, since in this type of engine the designer is limited seriously by the inherent compactness of the type in securing the proper strength and accessibility, as well as durability, of its various parts. With the cylinder and crankcase assembly developed satisfactorily, we will be ready to determine the advantages of this type in flight, which will involve testing its ability to work under various conditions of temperature, the power available at different altitudes and the advantages in maneuverability due to the compactness. There is considerable scope regarding this whole problem, but I am glad to say that it is being attacked with enthusiasm by the Air Service and by individual engine designers in this Country.

CYLINDER ACTIONS IN GAS AND GASOLINE ENGINES

BY SIR DUGALD CLERK

THE distinguished author begins with a short account of the principal actions common to all internal-combustion engines and then proceeds to a more detailed account of the experiments that have been made to develop the theory and establish the properties of the flame working fluid of those engines.

The divisions of the paper are headed (*a*) short statement of cylinder actions, (*b*) the air standard, (*c*) flame the actual working fluid, (*d*) knocking, pinking and detonating, (*e*) air and exhaust supercompression, (*f*) residual turbulence, (*g*) gaseous explosions, (*h*) flame propagation and recompression, (*i*) the specific heat of flame, and (*j*) conclusions.

After treating (*a*) in considerable detail, the author discusses present efficiencies and knowledge in regard to the limits of the thermal efficiency possible in internal-combustion engines under (*b*), (*c*), (*d*) and (*e*), going into considerable detail and presenting and analyzing numerous diagrams and charts. Under (*f*) reference is made to the author's paper on the theory of the Gas Engine and the experiments of the late Professor Hopkinson are discussed. The subjects under (*g*), (*h*) and (*i*) are then elaborated upon, illustrated and described in a comprehensive manner, many data and analyses being presented in support of the author's thought. His conclusions refer directly to the cause of detonation and methods of preventing it. [Printed in the July, 1921, issue of THE JOURNAL]

THE DISCUSSION

D. ROESCH:—In summarizing, it seems that the following outstanding points are particularly worthy of consideration and discusson. The increase of flame propagation is a function of turbulence. More rapid flame propagation is in accordance with Beau de Rochas' principles and is basicly a desirable condition. In fact, high-speed engines would be impossible without this feature. With regard to turbulence from high inlet-velocities, from flame projection and from inherent combustion-chamber shapes, the final decision will be a compromise.

When inspection is made for possible gains, the air-standard efficency should not be used. The ideal efficiency should take note of the actual gases under consideration and also their specific heats at the various temperatures encountered. The difference in results obtained from those two methods is large. Another variable occurring at this point is that introduced by the maximum temperature obtained. This factor is of relatively small importance. Values of variable specific heats are available for this work. Profeshor Goodenough's book on Thermodynamics shows the method of making the computations. Because of the introduction of the variable specific-heat factor, the method involves a solution by trial and becomes laborious.

The introduction of air or cool exhaust-gases is suggested and urged. Considerable work along this line has been done. The methods of application may vary greatly. The one used by Sir Dugald Clerk is that of being under pressure at the end of the suction stroke. Another is that of being under atmospheric conditions at the beginning of the suction stroke. Observation of the action of such an engine in 1908 showed that, with air introduction in a scavenging-type engine, an actual mean effective pressure of 130 lb. per sq. in. was developed. For engines of this date, this was about 30 per cent above good practice and I believe represents high present-day values. This was a 19 x 25-in. engine operating at 175 r.p.m. on natural gas. Pure air was given a lead over the mixture and in this way permitted any degree of scavenging possible without danger of loss of mixture through the exhaust valve by over-scavenging. In the case of air or exhaust-gas introduction under pressure at the end of the suction stroke, attention must be given to the increased compression resulting from the higher initial pressure. In the case of carbon-dioxide introduction, dissociation is probably easier than in the case of steam or water introduction. The endothermic reaction resulting with carbon dioxide may be more available to reduce temperatures and favorably affect detonation troubles than is the case with water. However, the high nitrogen content must be considered.

The best method of analysis involves isolation of the contributing factors so far as possible. First, we can picture conditions by similes that more or less accurately represent the matter under investigation. For example, in the case of obtaining homogeneous mixtures, we know that, by volume, gasoline and air ratios are about 1 to 9000, while city gas and air mixtures may be to 1 to 6. An inherent handicap is placed on the gasoline engine. If one tries to mix a bottle of India drawing-ink with a tub of milk, one will have some difficulty in eliminating streaks. The streaks must be eliminated from the mixture of gasoline vapor, air and residual burned gases. The mixture can be pictured in the case of gasoline vapor and air as a flat sheet of absorbent cotton wet with aviation

gasoline. The sheet will burn comparatively fast. If we add some other materials to represent the residual burned gases, we can make the picture complete. Let us take asbestos wool wet with carbon tetrachloride for this substance and mix it in various ways with the highly inflammable gasoline-soaked cotton. By picturing the even distribution of the asbestos throughout the cotton we have ideal conditions, considering that the asbestos must be tolerated. Substantially uniform and maximum flame propagation results. With the asbestos unevenly distributed, the spark may occur in a relatively slow-burning section and get a bad start, or it may pass through a section of mixture rich in asbestos which slows up the flame propagation. The simile is useful in further exercising the imagination.

While these methods of inspection have their value in understanding matters better, definite exact inspections are more positive in the results attained. The laborious processes required sometimes delay and prevent their use. As an example, we find too little use of the temperature-volume and temperature-entropy diagram. Dr. Eddy gives a graphical method for transferring $p\ v$ diagrams in $t\ v$ and $t\ \phi$ diagrams.[2] However, the method uses constant values of specific heats, and if possible should be revised to care for the variable specific heats. This revision represents laborious work, but it is firmly believed that study along this line will pick out the details of heat interchange during compression, explosion and expansion, that will answer many of the questions now unanswered. The use of this method for a number of years as a collegiate thermodynamic exercise has demonstrated its value in imparting a better understanding of these rather intangible functions. Its value could be greatly augmented by the revision mentioned.

It would be well to emphasize that analyzing conditions at full load is only part of this work. Practically the entire discussion is for full-load conditions and we all know that efficiency ratios must be high for part as well as full load. In fact, the objection of high-powered engines being so wasteful could be overcome only by laying more stress on the light-load and low-compression conditions. A similar condition was present in the case of gasoline-consumption tests before the Society's recommended engine tests, for full, three-quarter, one-half and one-quarter load, came into extended use. The complete representation of the gasoline consumption for all loads and speeds can be represented by a surface. I described this method in a paper entitled Testing Variable-Speed Engines by a New Method.[3] This has proved to be a valuable means for showing the desired data concisely.

Similar means should prove equally valuable for comparing the relative merits along the lines of efficiency ratio and establishing standards of desirable performance.

MR. BREWER:—A period of great activity in research work upon the internal-combustion engine began in England in 1906 among several investigators. This included Professors Hopkinson, Watson, Burls, Callendar and Burstall, and other men in connection with the work of the Gaseous Explosions Committee. These men followed various lines of research and their findings are handed to us in the form of reports and papers presented before the several scientific institutions. They have established definite facts, from practical and scientific viewpoints, upon which all of the technical side of the automotive industry is based. The thermodynamics of the engine, including data relating to heat flow, temperature distribution and the specific heat of the fluid, were developed to a remarkable extent in the few years following. At the same time fuel and carburetion were investigated more seriously by myself and others. Sir Dugald Clerk took a very great and practical interest in all this work, and did much to assist the younger men, this attitude being typical of him.

At present, with the exception of the undertaking of one of the large oil companies, very little research work is going on in England, although further work is contemplated, and there is no doubt that Sir Dugald Clerk will be most interested in any work that may be done in America as a result of his paper. In 1906 he gave us a leader in his paper on Exhaust Gas Analysis as a means of determining engine performance. He said at the time that the results of analysis alone might be misleading, but that they must be interpreted in connection with the findings of other engineers and applied accordingly in order that the full benefit might be derived therefrom. Heat losses are not always of the magnitude originally conceived. For example, it has been proved definitely that the heat loss to a piston is only from 12 to 16 per cent of the total heat loss into the walls. This is much lower than is usually supposed, and the loss to the water-jacket is not due to direct radiation from the flame only at the time of combustion in the engine.

In his paper on the Limits of Thermal Efficiency, read before the Institution of Civil Engineers in 1907, Sir Dugald Clerk stated that the exhaust loss is under-estimated and the water-jacket loss is over-estimated because, when the exhaust-valve opens, the hot gases discharging around the valve impinge violently upon the water-jacketed metal in the valve-pocket before their direction is changed. In violent motion, these gases impinging against a metal surface lose their heat very readily, so that some heat which should appear in an exhaust-calorimeter reading appears in the water-jacket. There is an interesting fundamental feature in connection with thermal losses and this is the base H, which is the total loss of heat to the exhaust and the water-jacket in British thermal units per minute. All the heat losses and temperatures in the engine are correlated to this value, and Hopkinson shows his temperatures of various parts as a ratio to this value. Briefly, Hopkinson found in his series of experiments in 1907-1908 that the ratio of the temperature at the center of the piston to the value of H never greatly exceeded 0.200, that it was approximately 0.170 toward the side of the piston and that the fall of the temperature from the center of the piston to the water-jacket is proportional to the square of the distance from the center. About one-half of the temperature-drop occurs between the center of the piston and the oil-film, the remainder of the drop being between this film and the water. In no case is the inside wall of a cylinder at any temperature that is likely to be more than about 60 deg. cent. (140 deg. fahr.) above the temperature of the water. This is a point not always realized.

The heat loss from the underside of the piston also was determined to be between 2 and 3 per cent and the radiation from the top of the piston 12 to 16 per cent of the loss to the walls; so, it is evident that attempts to cool an engine by the circulation of air across the underside of the pistons can have only a small possibility of success. Experiments were made to determine the temperatures and conditions producing preignition. For this purpose a bolt 4 in. long was screwed into the exhaust-valve cover so as to project into the center of the compression

[2] *Transactions of the American Society of Mechanical Engineers*, vol. 21, p. 275.

[3] See TRANSACTIONS, vol. 12, part 1, p. 338.

space. After the engine was started, the temperature of the bolt would shortly attain a steady value, at which if not high enough to cause preignition, it would remain. A temperature of 700 deg. cent. (1292 deg. fahr.) could be maintained without apparent effect with ordinary mixture proportions; enrichment of the gas charge caused the temperature to rise farther, with the result that ignitions would begin and an abnormal rise in the temperature of the bolt would follow. At 710 deg. cent. (1310 deg. fahr.) the phenomenon would start and, when the temperature of the bolt reached 740 deg. cent. (1364 deg. fahr.), the effect was so severe that the engine would pull up. Some years previously Hopkinson showed that, when an explosive mixture is ignited from one point, the gas at the point of ignition is very much hotter than at a distant point. The reason for this is that the gas at the ignition point is first ignited almost at a constant pressure and is then compressed during the progress of the flame. The hottest place in the gas is at a small distance from the bolt. When oil was dropped onto the center of the exhaust valve, preignitions were produced when the temperature of the metal was as low as 450 deg. cent. (842 deg. fahr.), the ignition being due to the liberation of hydrogen as the fuel became split up. Ignitions may be caused by oil in this way, but they will be intermittent only.

Professor Hopkinson has stated that the investigations of Sir Dugald Clerk and others have proved that the work done by an engine developing 60 hp. could be increased only by one-eighth by conservation of the loss of heat and, further, that if the rate of heat-flow were known for every instant of time and for every point of the inner surface of an engine cylinder, it would be possible by a sufficiently elaborate mathematical analysis to determine the various temperatures inside the cylinder walls. Sir Dugald Clerk propounded what he termed his unit of heat loss as the cubic-foot degree, which is the amount of loss of heat in a cubic foot of mixture cooling through 1.0 deg. cent. (1.8 deg. fahr.), and he showed further that the loss of heat in an engine cylinder was 400 cu. ft. deg. per sec. per sq. ft. of surface.

Hopkinson analyzed these losses in an engine, the superficial area at the instroke being 2½ sq. ft. and at the outstroke 8 sq. ft. He showed that if all the heat were given to the surfaces of the piston and compression-chamber, the rate of heat-flow over these portions would be 640 B. t. u. per sq. ft. per min. as a superior limit and, taking an average area of 5 sq. ft., the rate of heat-flow in round numbers was 300 B. t. u. per sq. ft. per min. As an indication of the meaning of these figures, a bare steam-pipe at a temperature of 200 deg. cent. (392 deg. fahr.) loses heat by radiation and conduction at the rate of about 10 B. t. u. per sq. ft. per min. Considering the cylinder liner, the average rate of flow of heat through the metal will not exceed 600 B. t. u. per sq. ft. per min. and, to sustain this flow, a temperature gradient of about 60 deg. cent. (140 deg. fahr.) per in. of thickness is necessary, according to the experiments of Callendar and Nicolson on the thermal conductivity of cast iron. Thus, the inner surface of the cylinder liner can nowhere be more than 60 deg. cent. (140 deg. fahr.) hotter than the jacket water. Hence, the temperature is no higher than in the walls of a high-pressure steam engine.

Regarding the piston, the radiation considered as from a thin disc of radius a and thickness t, which is receiving heat at the rate H per unit area, is $Ha^2/4kt$, where k is the thermal conductivity of the metal. If the heat-flow in the piston face is taken at 300 B. t. u. per sq. ft. per min., H will be 2.1 and k, according to the above authorities, is 0.064 at 180 deg. cent. (356 deg. fahr.), the other units being the inch, the British thermal unit, the minute and the centigrade degree. It is thus found that the temperature at the center of the piston will exceed that at the edge by 180 deg. cent. (356 deg. fahr.) approximately, when $a = 5.75$ and $t = 1.50$ in.

The heat given to the valve face is removed mainly by conduction along the stem and through the seat, and a sufficient fall of temperature must exist to cause this conduction. When a valve is coated with non-conducting material, the rate of heat reception will be nearly as fast as to clean metal, even though the temperature may be 300 or 400 deg. cent. (572 to 752 deg. fahr.) higher, so that a greater temperature gradient must exist accordingly.

The thermal calculations are all based on the value H, which is the total heat removed from the engine by the water-jacket and radiation in British thermal units per minute, and an average value of piston temperature gives the excess of center temperature over the mean jacket temperature of 300 deg. cent. (572 deg. fahr.) to 390 deg. cent. (734 deg. fahr.), the ratio of this temperature to the total heat, H, being between 0.207 and 0.198 respectively. At the edge of the piston the values of these ratios were between 0.175 and 0.164 respectively, and it was proved that these ratios were the same within probably 2 per cent whether the total loss was 1300 or 2000 B. t. u. per min. This proves that, within these limits, the proportion of heat received by the piston is substantially unaffected by the strength of the mixture. The highest recorded temperature at the center of the piston was 480 deg. cent. (896 deg. fahr.). It follows that the rate at which the heat is flowing into the piston face is 1.85 B. t. u. per sq. in. per min., when the total flow into the engine is 1600 B. t. u. per min., and this is the difference between the heat given by the gas to the metal and that lost by the metal by convection and radiation from the back of the piston.

To settle what the value of the radiation from the back of the piston would be, experiments were made which showed that, when the back was lagged, the temperature at the center was not more than 10 deg. cent. (18 deg. fahr.) higher with the lagging than without it. Not more than 2 or 3 per cent of the total heat received by the piston is lost from the back. The heat lost from the piston face was 12 per cent of the total heat-flow into the walls, compared with Professor Burstall's engine, which absorbed 16 per cent of the heat carried away by the cooling water. The proportion of heat received by the piston is considerably smaller than is imagined generally, as the area amounts to 30 per cent of the total exposed surface and it remains in contact with the hot gas during the whole stroke; even on the outer center it constitutes 11 per cent of the whole surface. This small absorption of heat is attributable only partly to relatively high temperature, for the excess of the temperature of the piston over that of the other parts of the engine, although considerable, is still a small fraction of the difference between the mean temperature of the gas and that of the metal. Probably a heat loss of 300 B. t. u. per min. occurs during the time when the hot gases rush past the exhaust-valve at the moment of release. Practically the whole of this loss goes to the valve and passages and none to the piston.

In regard to the exhaust valve, with a rich mixture the mean value of the relation of the temperature to H was 0.217; with a lean mixture it was 0.240. In the inlet-valve, with a rich mixture this value was 0.127; with a lean mixture, it was 0.134. Under ordinary conditions

the temperature at the center of the exhaust valve was 400 deg. cent. (752 deg. fahr.); at the inlet valve, it was 250 deg. cent. (482 deg. fahr.). There was a decided decrease, 10 per cent, in the ratio of the temperature of the exhaust-valve to H when the strength of the mixture was increased, the explanation being that the heat loss occurring during the outflow of the exhaust gas just after release goes mainly to the valve, and that this part of the heat is not much less in absolute amount with a weak than with a strong mixture. The temperature does not diminish in proportion to the heat supply, because there is a small percentage of heat loss with the weaker mixture, more going into the exhaust. Thus, the loss to the exhaust-valve in this way forms a greater proportion to the whole loss when the mixture is weak. The temperature of metal at any point is determined by the rate at which the heat passes into the surface per unit area and the distance that the heat must travel to the place where it is removed. In geometrically similar engines of different sizes, the distribution of temperature will be similar, but the temperature at corresponding points will be approximately proportional to the linear dimensions; that is, if the thickness of the piston face is halved, the fall of the temperature from the center to the edge would be doubled approximately and preignition probably would occur with heavy charges.

H. L. HORNING:—Mr. Brewer referred to the area between the valve-pocket and the cylinder proper. That is very important. The gas must be put through a very narrow passage to maintain velocity.

I recommend the reading of a paper by W. A. Tookey, an Englishman, on the Testing of Gas Engines. He brings out fundamentals of great importance. I think Professor Dixon's work also is excellent. I advise that Ricardo's recent articles in the *Automobile Engineer* be studied. They are fundamentally correct, as are the articles by Tizard and Pye on the Changes in Specific Heat. There is nothing better in all the literature on the subject. Ricardo has fallen into an error in his chemistry, however, in that he uses very impure hexane and heptane of vegetable origin in his research, getting vastly different characteristics from those two closely related paraffins that are alike in structure and of nearly the same molecular weight.

SIR DUGALD CLERK:—I take much pleasure in thanking Professor Roesch for his careful and appreciative summary of my paper. There are very few points that I desire to mention further. The air standard has proved very useful in providing a definite means of comparison for engines using varied compression-ratios and shapes of combustion space. It enables us to establish a figure of merit; that is, a value for the efficiency ratio as between the results actually obtained from a particular internal-combustion engine and those that could have been obtained had the working fluid been pure air and no heat or other loss been incurred to the cylinder from the enclosed hot air.

In my Royal Society paper of 1906 and Institution of Civil Engineers paper of 1907 I established the ratio 0.65 as that given by the best engines of that time and I pointed out that using actual specific-heat properties of a coal gas and air working fluid, the actual working fluid ideal efficiencies should be broadly 20 per cent less than air-standard values. I also pointed out that for all ordinary coal-gas engines the actual working fluid values could be easily obtained by using a gamma value of 1.285 instead of that of 1.400 of the air standard.

The efficiency formula has then an exponent 0.285 instead of 0.400 and the actual working fluid consisting of nitrogen, carbonic acid, steam and some excess of oxygen, gives efficiencies E for varying compressions.

$$E = 1 - (1/r)^{0.285}$$

For compression-ratios of 3, 4, 5, 6 and 7 the ideal efficiencies of the actual working fluid are very nearly as given in Table 1.

TABLE 1—APPROXIMATE IDEAL EFFICIENCIES OF ACTUAL WORKING FLUID

$1/r$	3	4	5	6	7
	0.269	0.326	0.368	0.400	0.426

Prof. H. L. Callendar arrives at the same value of Υ by a different method as mentioned by him in the discussion of the 1907 paper. This takes note of the change of specific heat with temperature without requiring the use of the laborious method of successive approximations.

I have used varied methods of introducing cool exhaust and in the large engines of the National Gas Engine Co. I have caused the exhaust gases to be drawn into the cylinder with the charge. The method of adding under pressure is adopted only when it is desired to obtain the higher mean pressures due to super-compression. I am in full agreement with Professor Roesch as to the necessity of considering light-load conditions down to one-quarter load and even lower. There is still much room for the investigation of light-load efficiencies.

I have not mentioned exhaust-gas analysis in the paper but I fully agree with Mr. Brewer as to the substantial help to be obtained by the practice of such analysis. I presented a paper entitled The Principles of Carbureting as Determined by Exhaust-Gas Analysis, to the Institution of Automobile Engineers in December, 1907.[3] This followed tests made at a Royal Automobile Club trial of 12 cars under ordinary conditions of running on the road. The method has been used ever since that trial. Mr. Brewer also alludes to my investigation of the effects of suction turbulence, now generally acknowledged as of vital importance in the action of the gasoline engine. I agree with Mr. Brewer's summary of the work of the British Association Gaseous Explosions Committee, of which I am chairman.

I thoroughly agree with Mr. Horning's remarks on the importance of Mr. Tookey's work on gas engines. Mr. Ricardo's work also is of great importance. I shall watch with interest the experimental work of the younger American engineers, whose investigations appear to me important and ingenious.

TURBULENCE

BY H. L. HORNING

THIS paper is a collection of notes gathered from investigation of the subject in the literature on the development of internal-combustion engines and memoranda set down during a long series of tests. The paper includes a discussion of the physical and chemical aspects of the subject and sets forth a working theory that has proved of value. Several methods of measuring turbulence are stated.

After outlining the history of the subject and giving references, the effect of turbulence on flame propaga-

[3] See *Proceedings of the Institution of Automobile Engineers*, vol. 2, p. 47.

tion is discussed at length and illustrated by diagrams. Two methods of producing turbulence are then copiously illustrated and described, inclusive of seven diagrams showing characteristic turbulence in typical cylinders.

Following the description of the methods of measuring turbulence, the effects of turbulence in performance are summarized under 10 specific divisions. [Printed in the June, 1921, issue of THE JOURNAL]

THE DISCUSSION

H. M. CRANE:—We built an L-head engine and a valve-in-head engine of practically identical characteristics. As to power, the actual results in service were almost identical. We obtained a slightly higher mean effective pressure from the valve-in-head engine. We designed it originally with a 25-deg. spark-advance. In the first test we could get no power and it sounded like a two-cycle motorboat engine. We know now that this was due to the after-burning in the exhaust. The final result in that engine was that we required from 60 to 65-deg. spark-advance to maintain the maximum power at the peak of the power curve, at 2500 r.p.m.

The equivalent L-head engine gave the same results with only a 25-deg. spark-advance. Fortunately, we were able to add a second spark-plug to the valve-in-head engine. The spark-plugs were diametrically opposite each other; we put in two at right angles to the center-line of the valves. With the two spark-plugs we were able to reduce the maximum spark-advance to 30 or 35 deg. The engine ran considerably more smoothly with the two spark-plugs than with single spark-plugs. In idling we found another extremely interesting condition. With two spark-plugs and a careful idling adjustment, we would get a certain result. If we cut out either set of spark-plugs, it was necessary to enrich the mixture nearly 25 per cent to get the engine to idle. Of course, that is due to the fact that it is a low-turbulence engine in every respect; at idling speed there is practically no motion in the mixture. On account of the form of combustion-chamber there is no segregation of mixture such as obtains in an L-head engine. Occasionally we would get a burnable mixture and at the next attempt we would not; the engine simply would not operate satisfactorily. The weakness of the low turbulence and big spark-advance lies in the fact that the engine is igniting at a very low compression. That is the unforunate part of it. With a 65-deg. spark-advance on an engine of any normal proportions we are not nearly utilizing the compression that we are supposed to be realizing; the engine is actually still compressing after ignition. I think that is bound to affect the results adversely. The advantage of the overhead-valve engine is that it has a much better shaped combustion-chamber. In our experience with respect to detonation the improvement in the shape of the combustion-chamber over that of the L-head engine, which is not very good in that regard, was sufficient to obliterate entirely the difference in the turbulence. that is, granting that the turbulence was far greater in the L-head engine, which I am sure it was.

Those tests show that the turbulence we can do real business with is that produced during the compression stroke. that is, the turbulence produced during the inlet stroke in an ordinary engine dies away, in the overhead-valve engine especially. As to the direction of turbulence in the overhead-valve engine, I think that Fig. 8 of Mr. Horning's paper is not exactly a true representation of all cases. For instance, an engine with the valves in the longitudinal center-line of the engine has the inlet pipe at right angles to the longitudinal center-line; the mixture enters the port on a distinctly tangential line, and I think that in no ordinary design of engine the streamline in the valve-port is sufficient to straighten out the turbulence. In other words, there is a whirling turbulence, such as it is, in that type of engine; it will not be a perfectly vertical turbulence as if the mixture came in straight as in Fig. 8 of Mr. Horning's paper, and one must bear that in mind when searching for the spark-plug position because, undoubtedly, it has a bearing on it. We are now working on an overhead-valve engine with four spark-plug locations available, and will be able to explore and see what result we can get.

Another confirmation of Mr. Horning's statement regarding the detonation in the L-head engine is that in a number of engines of ours that were rather bad on detonation in certain ways, a tremendous improvement was brought about by using aluminum pistons. The result was that we removed the hot-spot that was farthest from the spark-plug, the spark-plug being located normally over the inlet port; the engines are of the L-head type. I have tried the spark-plug over the exhaust port and I think there was a slight advantage. The two valves were so close together that it would take a trained observer to decide that there was any difference. There is no question that there is a difference between using an aluminum and a cast-iron piston. In the overhead-valve engine, especially when using two-point ignition, I doubt whether there is any very noticeable difference between aluminum and cast-iron pistons. We certainly did not notice any in the tests that we made. In other words, the more we work on this subject, the more we will find that we are converging on a given point of knowledge that will be fairly definite; but, unfortunately, it is almost impossible to combine violent turbulence with a very good form of combustion-chamber; so we must bear in mind that we are working with compromises all the time, and that we cannot say now that an L-head engine is the only one to use because we can get a very high turbulence with it, any more than we can say that an overhead-valve engine is the only thing to use.

PROF. ROBERT E. WILSON:—I think there can be no doubt about the essential validity of Mr. Horning's conclusions as to the value of turbulence. However, in the explanation that he offered for this result, he assumes that turbulence increases the number of collisions between the reacting molecules and thereby increases the rate of reaction. I believe that this cannot be substantiated; to illustrate why, assume that all the people in a room are moving about violently; the number of collisions that they have with one another will be determined by the number of people in the room and by the rate at which they are moving. Merely superposing on this rapid vibratory motion a mass-motion of the room as a whole in a single direction will not affect the result in the slightest. The fact that the earth is rotating and that we are all going forward at enormous speed has no influence on the number of collisions that would happen in this supposed room. It is the same with the molecules. They are moving back and forth at enormous velocity. Simply superposing a comparatively slow mass-motion would have no effect, because 500 ft. per sec. is nothing at all compared to the molecular speed of vibration. Of course, if one side of this room I mention were moving much faster than the other, it might increase the number of collisions, but even that factor could not enter, in Mr. Horning's case, because the rate of motion is very small compared with the rate of molecular vibration.

I think Mr. Horning's other suggestion with regard to eliminating dead pockets and such effects is much more likely to be the explanation of the value of turbulence.

May not the localized deposition of carbon that Mr. Horning mentions be due to the burning off of the carbon from the hottest part of the pistons?

W. S. JAMES:—The presence of exhaust gas in the explosive mixture has a marked effect on the leanest mixture on which an engine can operate. We have found that, as the throttle-opening is decreased, the engine cannot run with as lean a mixture as at full-throttle. Why is this? At the end of an exhaust stroke, regardless of the load on the engine, there is a practically constant weight of exhaust gas in the clearance space. This weight may vary slightly with the exhaust temperature, but is otherwise independent of engine speed or load. If the turbulence of the cylinder charge is increased, the exhaust gas mixes with the incoming charge and reduces its inflammability. The result is that we cannot fire as lean a mixture as we can when we have a completely fresh charge. It seems to me, therefore, that turbulence is good as long as we can control it, but this is probably difficult to accomplish. In an engine cylinder, if we can stir the fresh incoming charge and still keep it separate from the exhaust gases, we will have effective turbulence. If, however, we mix the fresh charge with the exhaust very thoroughly by turbulence, we will lose in maximum economy. This fact may be overlooked, as it is so well known that exhaust gases exist that we forget about their presence.

In the derivation of the expression for air-cycle efficiency as given in the classical works, we find that about eight assumptions are made. At least five of them are included among the factors that Mr. Horning has grouped in his expression for combustion efficency. After considering the derivation of air-cycle efficiency and the assumptions made, we realize that air-cycle efficiency is the efficiency of expansion and nothing more. It is the efficiency of the expansion ratio; all the other factors involved in combustion and the faults of fuels and fuel mixtures as they exist are assumed to be zero. When we talk about air-cycle efficiency, let us remember that it is simply the completeness of expansion. If we know the other factors, such as the variation of specific heat with temperature and pressure, the difference between the ratio of specific heats on the expansion and compression strokes and the fact that a fuel mixture does not burn instantaneously at the time of ignition, let us blame them on the fuel and not on the engine cycle.

H. C. GIBSON:—I agree with Mr. Horning that turbulence aids wet mixtures. A Knight engine is one of the best instruments for the production of turbulence. The intake gases rushing along into the cylinder have an absolutely clear passageway thereinto; there is nothing to obstruct them in the slightest degree or to reduce their speed. Their plane of entrance to the cylinder permits them to continue the motion in a whirling manner within the cylinder. The consequence is that they come to a condition within the cylinder after the closure of the port where their original speed can be maintained more readily. It is easy to understand that, with this form of engine, we can have far greater turbulence than with any form of engine using valves; and Knight-engine turbulence will maintain itself for a longer period. Residual exhaust gases exist and their proportion is greater in ordinary use the more the throttle is closed but, to have an engine operate satisfactorily to the customer, irrespective of the number of miles attained per gallon of fuel, every cylinder must fire regularly. With wet mixtures, the greater the turbulence one can attain in the cylinders under throttled conditions, the more certain the firing of the charge will be, but throttling is the very worst condition for obtaining turbulence in the cylinder because the major turbulence occurs at the throttle. By using really evaporated fuel we can mix the active charge thoroughly with the exhaust gases and produce approximately the same conditions in each cylinder of the engine better than we can with the poppet-valve type of engine, and the loss of turbulence after the gases pass the throttle is no detriment.

W. G. GERNANDT:—Is the increased efficiency of this type of combustion-chamber due to turbulence rather than to localizing the mixture where the flame propagates for the least distance?

MR. HORNING:—Mr. Crane's remarks to the effect that the representation in Fig. 8 of my paper of the turbulence in an overhead engine is not a true representation of all cases for that type of engine, are correct. Each engine has its peculiarities. Fig. 8 shows what we could deduce from the knowledge of the following governing factors: (*a*) location of intake; (*b*) direction of gases entering cylinder; (*c*) shape of top of chamber; and (*d*) the direction of the gas currents at the time of ignition as deduced from the engine performance with the spark-plug in various places.

Professor Wilson's remarks regarding my explanation of why turbulence causes increased flame propagation are pertinent. I did not wish to convey the idea that more contacts are made between the molecules in a given time because of turbulence. The thought I desired to express is that when the mixture is circulating at a high velocity past the spark-plug at the instant of ignition, small reaction or combustion nuclei are scattered in great numbers throughout the mixture, approximating the effect of a vast number of spark-plugs. The chances of such contacts in a given time are greatly increased where turbulence increases the number of initial reaction points.

Mr. James' figures as to the number of contacts and molecular characteristics are very interesting and his remarks regarding the effects of exhaust gases, known sometimes as residual products of combustion, are to the point. I agree fully with his view as to the effect of the relatively greater proportion of inert gases by weight as the load decreases. If the products of combustion could be kept quiescent and segregated while the combustible mixture was turbulent at the time of the spark, the process would be carried out with great efficiency. This contention of Mr. James is correct. There is a point of practical interest that adds great value to his suggestion, namely the question of the leanest mixture that can be burned is decided by the leanest mixture that can be ignited; a distinction of great importance. It is known that after ignition is well started in a rich mixture, it will propagate down into a mixture so low in fuel value that great performances in economy can be obtained experimentally by following this order of operation. It can, therefore, be said that after a certain proportion of the total combustible charge has been ignited, and a certain temperature or pressure reached by the explosion, it is immaterial whether there is complete, practical or partial segregation of the inert gases and it is relatively unimportant whether there is turbulences of the whole mixture or not. This fact may be of great value in putting into practice what Mr. James has so clearly pointed out.

Coming from so careful a student as Mr. James, the remarks regarding air-cycle efficiency are very interesting and a full understanding of them will no doubt bring about clearer thinking. There is no place where I have, to my knowledge, assigned to the air-cycle efficiency any other value than that arising from the expansion ratio. Mr. James has twice stated in his remarks that "air-

cycle efficiency is expansion ratio." I cannot help but feel that what he desired to state is that air-cycle efficiency is the efficiency arising from the expansion ratio of ideal air or working fluid whose specific heats do not change with temperature and the ratio γ of the specific heats

$$C_p/C_v = \gamma = 1.408$$

Tizard and Pye have called attention to the other ideal features of the cycle which is shown at the left of Fig. 14. These features are

(1) Compressed adiabatically in the ratio $V_a/V_b = \gamma$
(2) Instantaneously heated at the constant volume $V_b = V_c$ to its maximum temperature of t_c deg. cent.
(3) Expanded adiabatically to its original volume $V_d = V_a$
(4) Cooled instantaneously at a constant volume to its original temperature t_a deg. cent.

It will be noted that it is impossible to ever attain practical operation and have conditions which line up with these assumptions listed below.

(1) The working fluid does not have a constant ratio of specific heats at all temperatures
(2) The working fluid does not have a ratio exactly like that of ideal air
(3) It is impossible to compress adiabatically
(4) It is impossible to release the spark at the end of the stroke and it is impossible to add heat instantaneously at constant volume due to the slow burning of the mixture
(5) There is always dissociation of the products of combustion and some after-burning at the peak of the diagram which upsets the form at the peak and it is rare that we have a point c
(6) It is only approximately possible to expand a charge adiabatically, there being a considerable loss of heat during the first twentieth part of the stroke due to high temperatures
(7) It is impossible to lose heat from the point d to the point a instantaneously and the general form of the diagram at the top must be rounded off so as to exhaust early to get a complete exhaust
(8) The volume of the products of combustion of the usual gaseous fuels is less than the original fuels at the same temperature and pressure, while with gasoline and the liquid fuels it is more
(9) As a matter of fact, a loss due to radiated heat occurs throughout the cycle, which is not assumed in the cycle

These practical deviations from the assumption of the engine working on ideal air and the actual working fluid together with the other deviations listed above result in gains and losses from the performance to be expected. This causes a distinct loss, which, as outlined in Sir Dugald Clerk's paper, is between 30 and 40 per cent of the air-cycle efficiency. This loss is expressed as relative efficiency and this relative efficiency goes up and down according to the efficiency with which the mixture is burned. In an investigation in which the only changes in the factors are those affecting turbulence, since the net results of these changes are recorded in the performance through the ratio of the indicated thermal efficiency to the air-cycle efficiency, we have in this a valuable index to the value of any design with reference to turbulence. Referring to Mr. James' remarks on the matter analyzing the factors that make the loss accounted for in relative efficiency, I admit it takes a great amount of clear thinking to assign values based on the available data. However, I shall be glad to have Mr. James point out any defects that have crept into my paper or the above presented view.

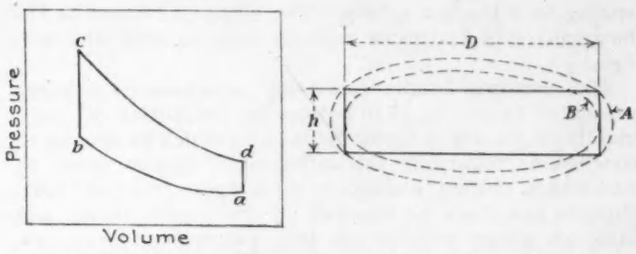

FIG. 4—AN INTERNAL-COMBUSTION ENGINE CYCLE HAVING A NUMBER OF IDEAL FEATURES AT THE LEFT AND AT THE RIGHT A DIAGRAM SHOWING HOW IT IS POSSIBLE TO INCREASE THE VOLUME OF A CYLINDRICAL CROSS-SECTION VERY MATERIALLY WHILE ONLY CHANGING THE AREA SLIGHTLY

As to his remarks regarding the number of molecular contacts in a second, I would state that initiating the flame at a great number of points gives the particles of gas a chance to distribute the flame quickly through the mixture by utilizing the kinetic properties of the gas to the best advantage.

I can confirm Sir Dugald Clerk's paper and the discovery of Prof. Bertram Hopkinson that the spark-plug is the hottest point in the cylinder, due to adiabatic compression.

Concerning Mr. Gibson's remarks on the Knight engine, I would say that I have been driving a Knight engine and want to confirm the statement that it is very efficient from a turbulence standpoint. Whether this is the cause of the very slight tendency to knock or whether a low compression-ratio is the cause, I do not know. On page 446 of the May 1921 issue of THE JOURNAL will be found results of tests made by me on a Knight engine. It is obvious that it would be disappointing to find a knock in an engine with so low a mean effective pressure. There is no doubt that turbulence was responsible for the excellent indicated thermal efficiency and the mechanical efficiency was remarkably fine for a stock engine.

The point Mr. Gernandt brought up is excellent. There is no doubt that the hemispherical combustion-chamber shown in Fig. 7 of my paper is a very good one from the standpoints that it is compact and has the spark-plug in a position so favorable that the distance is relatively short to all parts of the mixture. The flat section above the piston is very bad for detonation. It is interesting, however, to know that the mean effective pressure developed is to the mean effective pressure that could be developed by the energy contained in the total volume, as the volume of the hemispherical part is to the total volume of the combustion-chamber. In other words, the flat part enters into the combustion too late to contribute to the mean effective pressure.

One of the fundamentals in a combustion-chamber, as pointed out some years ago by L. H. Pomeroy, is, of course, the desirability of having as small a volume as possible of stagnant gas lying against the wall of the combustion-chamber. It seems impossible to determine the thickness of the inert layer and so we are only permitted through turbulence to drive the layer off into the burning sections. We can, however, try to keep the area with relation to the volume down to the lowest minimum. It is interesting to note the following methods of doing this. If we have a cylindrical cross-section, such as is shown at the right of Fig. 4, having a diameter D and height h, it is possible to increase the volume considerably while increasing the area only slightly by giving the chamber the ellipsoidal form shown by the bulging dotted lines A or B. This is the first step in an evolution

ending in a perfect sphere. The ellipsoid is next to the hemisphere in favorable ratio between volume and surface.

Mr. Pomeroy kindly called my attention to a paper presented by him in 1919 before the Institution of Automobile Engineers of Great Britain, in which he sets forth conclusions regarding the influence of engine speed on turbulence. I have studied it with great interest. Mr. Ricardo has made an analysis of the results shown and indicates pretty conclusively that gas velocity is of primary importance in the matter of determining the speeds at which the best performance can be expected. Numerous tests seem to show that it must be considered a first approximation inasmuch as the gas velocities at which the maximum brake mean effective pressures occur vary from the wide limits of 120 to 175 ft. per sec. It appears as a general rule that where it is desirable to attain very high values for the brake mean effective pressure and indicated thermal efficiency at speeds below 1000 r.p.m., the higher gas velocities will be necessary, that is to say, approaching the 170-ft. per sec. valve velocities. In engines where it is desirable to have maximum brake mean effective pressure and maximum thermal efficiency at speeds of 1800 to 2000 r.p.m., it is generally to be expected that gas velocities of the lower value obtain, at these speeds of from 120 to 150 r.p.m. The product of the gas velocities and the engine speed seems to tend to increase, roughly, at a less rate than the engine speed.

MR. BREWER:—We have supposed for a long time that combustion is complete at about one-tenth of the downward stroke of the piston in the cylinder bore; it should be, but it is not. What we are trying to do by turbulence and by other means is to obtain that completeness of combustion in that small interval of time. However, we know that, under certain conditions, the combustion is carried on to a later stage in the cycle of operations of the engine, and we suffer therefrom. We are trying to find why the combustion is delayed and exactly what effect the heat of delayed combustion is having upon the engine. The whole question hinges to a very considerable extent upon the source of the generation of heat, and upon the heat-flow from the time of maximum temperature.

To amplify what Mr. Horning said with regard to the generation of heat from one single point, I would point out that it was discovered by Professor Hopkinson that if an artificial heated surface were produced in the engine, which he accomplished by using a bolt fixed inside the combustion-chamber head, certain conditions would arise with regard to the temperature of the head of that bolt as the mixture strength was increased. With the normal mixture strength, when a temperature of 700 deg. cent. (1292 deg. fahr.) was reached in the bolt-head, the condition of stability was reached. When he enriched the mixture beyond that point, even though it were only about 1 per cent, ignition would start from the vicinity of the bolt-head and, as soon as ignition started from the vicinity of the heated surface, the rise of temperature of the heated point was exactly 10 times as rapid as it was before. In other words, in rising from 640 deg. cent. (1184 deg. fahr.) the temperature of the head had a certain definite increase in temperature rate amounting to 2.5 deg. cent. (4.5 deg. fahr.) per explosion, but as soon as the firing started from the neighborhood of this spot, the rate of temperature increase was 10 times as fast, until the engine refused to work. This shows that high temperatures are being generated from the source of ignition. Professor Hopkinson was definitely satisfied that ignition was not occurring from the metal of the heated surface, but only from the neighborhood of the metal. He showed further that when that heated metal was coated with carbon or any other material of a non-conducting character, this did not materially affect the phenomenon of heat being started from the hot zone.

G. P. DORRIS:—A possibility which I believe has not been mentioned is that in the combustion of the gas, as explained by Mr. Horning, the pressure is applied to the piston from two sources. There is first an expansion pressure due to the heat that drives the piston, but there is also the secondary force of the velocity of the gas being thrown against the piston. We can slide tons of airplanes on the air, which shows that the air is of a very definite weight. This combustion matter also is of some definite weight. If the rate of combustion is as fast as sound, as I understand has been stated, it is possible that, with Mr. Horning's combustion-chamber, he fires the mixture in a comparatively segregated combustion-chamber, from which it is blown into the main combustion-chamber with such velocity that the pressure is distributed more uniformly during the working stroke, therefore preventing the possible detonation and the knock that we have been discussing.

ELIMINATING CRANKCASE DILUTION BY MANIFOLD DEVELOPMENT

BY G. P. DORRIS

ABOUT 1917 the heavy ends of the fuel sold as gasoline required such an amount of heat to vaporize them that the expression "crankcase dilution" appeared; now they have increased to a maximum boiling-point of 446 deg. fahr., which has made it necessary to go still farther in the direction of heat application.

After a brief consideration of the relative heat-absorption of air and fuel and the time factor in its relation to vaporizing, the author describes experiments with a specially designed manifold for increased vaporization efficiency and presents photographs of the device.

With this type of manifold it has been possible to eliminate crankcase oil dilution completely and effect a reduction in carbonization. The lubrication efficiency has been improved, as well as other features that are enumerated. [Printed in the July, 1921, issue of THE JOURNAL]

THE DISCUSSION

MR. DORRIS:—In the new pipe, shown in Fig. 1 of my paper, the two center pockets are exhaust pockets that lead out to the side and down to the exhaust pipe. This was certain to throw the heavy ends against the hot wall and gasify as much of the fuel as possible at that point. The engine operated very well on the lighter gasoline, but we found that the four center cylinders were very much favored and that the two end cylinders were inclined to foul the spark-plugs and prevent operation.

We have had any number of cases where cars operated very satisfactorily until they got a dose of heavy ends from some gasoline station. It has required considerable effort to explain to the public why this is and to put the blame on the fuel and not on the engine. That has been one of the conditions that prompted us to continue this change to prevent liquid fuel from entering the cylinders. The bottles shown are 4-oz. sample bottles that we fill about one-half full when starting. This is a fairly crude arrangement, and it by no means collects all the fuel that trails into the two end cylinders. Since we installed this new pipe, we have noticed a material improvement in uniform distribution and it has actually quieted the engine considerably on account of the uniformity of performance of the different cylinders. We formerly used hot air with this arrangement, but on the new arrangement hot air is eliminated entirely.

Fig. 2 of my paper shows the first pipe we made after this change. The heater was put on to control the excessive heat. The gas was fed into the side of the pipe and passed through the top down into the different cylinders. The two pipes being cast together, the temperatures ran fairly high. The engine operated very clean and very sharp; in fact, there was very little drag to it but it was not fully up to its efficiency on account of the reduced compression. These bottles were installed to get a relative idea of the amount of gas passed over to each cylinder so that, if possible, we could arrange the pipe in such a way that it would make that as uniform as it could be made. That led us to tap the heavy ends back to the central pocket, so that it automatically boils them out and sends them over as vapor.

In the revised pipe shown in Fig. 3 of my paper, the exhaust is separated from the overhead admission pipe. It has sharp bends, where the velocity effect of throwing the gas over drops some of it into the cylinders and distributes those heavy ends; so that has its effect in uniform distribution. The large heater shown was installed temporarily to get some idea of the amount of heat required.

The final pipe, shown in section in Fig. 4 of my paper, leads the gas up into the carbureter through a heater that is controlled by checking the supply and outlet at exhaust atmospheric pressure. This gas is thrown over against a blind wall, so that it is not swept on over to the cylinder but is given an opportunity to drop the heavy fuel in the pocket between this exhaust pipe and a similar pipe on the opposite side. That provides an excellent still, a heating apparatus in which to vaporize this fuel.

The one fact that we have overlooked is the time element required to vaporize this heavy oil. Formerly it has been shot through at such a rate of speed that we about burned the skin off of each ball of gasoline and shot the core out at the exhaust pipe. After we had gotten this pipe into operation and had settled on a production pipe, we put in 1 gal. of kerosene to test the relative capacity of vaporizing even kerosene. I believe this test, resulting in our obtaining 17.1 miles on that quantity of kerosene, assures us that practically none of it was passed over to the engine cylinders. On this test that was not by any means the maximum that could have been obtained. It was simply run as a comparison to get some idea as to how the different fuels perform under identical conditions.

This whole procedure has unfolded many possibilities for further experiment that we have not as yet had time to continue, in seeing how far we can go with a cross between kerosene and gasoline and as to what troubles develop in a trend toward a kerosene engine. This will

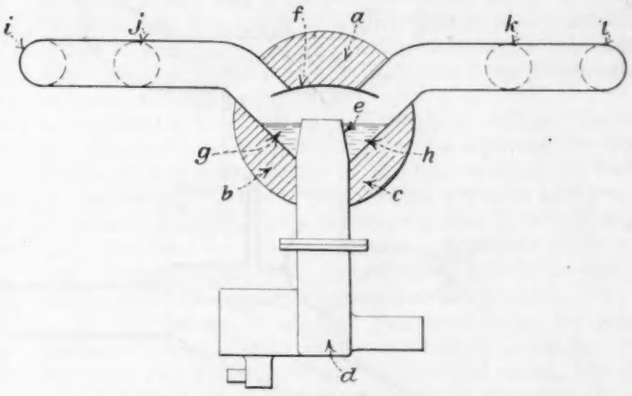

FIG. 5—SPECIAL MANIFOLD DEVELOPED FOR BURNING KEROSENE

be followed up immediately, but the results so far gained have been so gratifying that it is safe to state that we have improved the efficiency of our engines at least 10 per cent and they are absolutely free from crankcase dilution. In line with this and in regard to the two end spark-plugs that were fouling considerably and constantly, it is possible now to put in greased plugs and burn them clean, which seems to reverse the condition that we had formerly.

A. W. SCARRATT:—Fig. 5 is a sketch of an intake manifold that is burning kerosene, built on the same principle as the one described by Mr. Dorris. I showed this sketch a year ago at the Ottawa Beach Semi-Annual Meeting. The exhaust comes through the three areas *a*, *b* and *c*. The carbureter hangs down below, at *d*. In this manifold we get the maximum velocity at the end of the vertical intake-pipe, or nozzle, *e*. The gas in coming through the nozzle, due to its velocity, impinges against a sort of hemispherical or umbrella-shaped dome at *f*, that is a highly heated surface; it then travels under the edges of the dome and into the airstream. In making development experiments on this manifold we tapped into the basins *g h* to see how much of the heavy ends we could collect at those places. This is essentially just what Mr. Dorris did. The heavy ends do roll back on the manifold walls and gather in the pockets at *g* and *h* that are out of the main airstream and consequently in a slight vacuum. This manifold was developed for use on a 16-valve truck engine that we build, to improve the operation on gasoline. We had no idea at the time of using it for kerosene and, after experimenting in choosing the right size of manifold, we found that with a 155-deg. fahr. temperature at the intake ports at *i*, *j k* and *l* we obtained exactly the operation that we desired on gasoline. Through curiosity, we tried the same manifold on kerosene with the result that, without any change whatever, our temperatures on kerosene rose 30 deg. higher, or to 185 deg. fahr. at which heat we had complete vaporization. We made the outer arms of the manifold of glass so that we could actually see what was taking place in it. The manifold is standard on our truck engines at present, and will become standard equipment on our tractor models eventually. We have two 3½-ton trucks of very liberal dimensions throughout in operation with this manifold, using kerosene as fuel, and have had them in service all this past winter. In using gasoline throughout the winter, we were fortunate if we could obtain from 3 to 3½ miles per gal. in the ordinary pick-up and delivery work that the trucks are required to do. Our firm is in the structural steel business and occasionally the loads on the trucks are very excessive. We have been

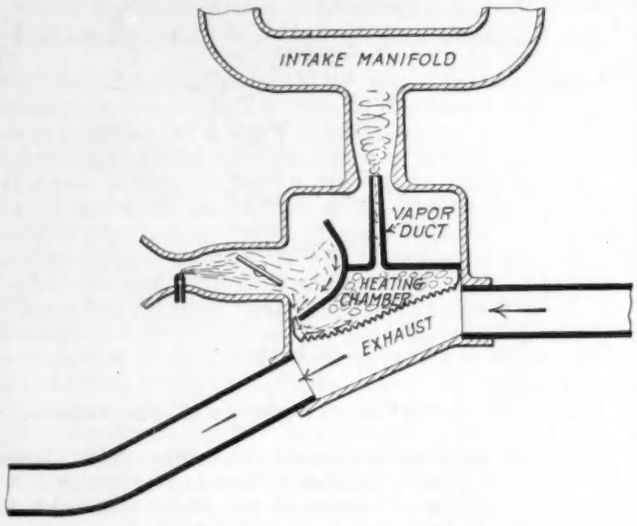

FIG. 6—A FUEL FEED SCHEME IN WHICH A SEPARATOR LOCATED JUST BEYOND THE CARBURETER IS UTILIZED TO SEPARATE THE LIQUID UNVAPORIZED GASOLINE AND PASS IT TO A HEATING CHAMBER FOR VAPORIZATION

keeping weekly records of the performance of the trucks running on kerosene. Recently one averaged 7.1 miles per gal. and the other 6.8 miles.

This same manifold equipment is used on our tractor engines for alcohol burning. We change the compression-pressure raising it to 110 lb. per sq. in. I was pleased at the confirming remarks[4] of both Mr. Midgley and Dr. Dickinson regarding the use of alcohol as fuel. We have to use alcohol as fuel on tractors in certain localities and have been forced to work out a vaporizing system which will handle it properly; this arrangement does so, although we have to apply a considerable amount of heat to the intake air. I sometimes think our minds are running in a groove. Some of us are hypnotized, I believe, by the word "petroleum." If we would remember that there are other things than petroleum that might be used as fuel and devise means to make them at a reasonable price, it would not cost nearly as much to learn how to get another fuel as it did to learn how to get the gasoline of today. If we should do that, we would solve the fuel-supply problem in part at least.

F. C. MOCK:—An additional reason for attacking the fuel problem in this way is, I think, that when successful we shall be through with the problem of distribution. I believe that within a few years we shall have reached a point where we shall have no distribution trouble, and we shall consider the practice of leading liquid fuel into the intake-pipe and from the intake-pipe to the valves as engineering barbarism.

Fig. 6 illustrates what I have in mind. The principle of having a separator just beyond the carbureter, separating out the liquid unvaporized gasoline, passing it to a heating chamber and allowing it, when vaporized, to rejoin the airstream is utilized. This was proposed a long time ago, and no originality is claimed for the idea. The difficulty lies in getting satisfactory separation, for this is really very difficult if there is any great quantity of liquid fuel to handle, but if one can accomplish such a separation, there is no difficulty in getting enough heat from the exhaust for fuels much inferior to kerosene. The limitation of temperature lies purely in how much the vapor will raise the total mixture temperature when it condenses again as it rejoins the airstream; and one can keep the temperature down by feeding cold air from outside the hood to the carbureter. If we can develop this principle of separation, and I am sure that it can, and will, be developed within a few years, it will open up a considerable extension of internal-combustion engine design, as there will be no limitations of manifold shape, or air velocity, because the manifold will be handling a fog. In an engine design where it is desired to have the intake-valve ports on the opposite side of the engine from the exhaust, this heating chamber and the carbureter can be put on the exhaust side of the engine and a connection made to the intake across or through the engine.

By the development of this idea, and the work which Mr. Midgley and his associates are doing in developing an anti-knock element, I think we shall have the automotive fuel problem pretty well solved within a few years.

MR. HORNING:—I wish to support Mr. Dorris, Mr. Mock and the others in what they have said and to emphasize fundamental facts. One of the great losses in power in an engine today is due to the fact that we are dealing with fuel as a liquid. A fundamental in chemistry and physics is that one cannot burn a liquid. Combustion is a phenomenon of combinations of substances at a rapid rate, and they cannot combine rapidly enough to generate heat unless they are in the form of gases. We are putting into engine cylinders liquid that cannot enter into the combustion and cannot contribute toward power, and one of the great sources of power loss is that we are not getting out of the fuel an amount of energy that is in it. This is the carburetion efficiency that I have mentioned before and becomes a large factor in badly distributing systems.

Recently, we investigated so-called hot-spots. We used a manifold equipped with various devices and arranged to supply 1 lb. of fuel to the carbureter, taking off all the heavy fuel that was deposited on the wall of the manifold. We collected the unvaporized fuel in the manifold, just before it entered the cylinder. At 400 r.p.m., running idle, we took out 50 per cent of the fuel and the engine did not show it; the engine ran just as well. This 50 per cent was in the form of a liquid that had a specific gravity of from 48 to 51 deg. Baumé. The original fuel had a gravity of 58 deg. Baumé. We should be able to transform the 50 per cent loss into a gas that we can burn.

The difference in temperature is not an inherent characteristic of the manifold; it is a physical characteristic of the fuel. The heat of vaporization controls it. One can change an engine from gasoline to kerosene and see the temperature rise automatically. The first time I did that I thought I had designed a wonderful automatic manifold. However, the fuel was entirely responsible. It takes less heat to vaporize kerosene than it does to vaporize gasoline. It requires 140 B. t. u. to vaporize 1 lb. of gasoline and 105 B. t. u. to vaporize 1 lb. of kerosene. It requires a higher temperature to vaporize kerosene, however, and we ought to consider that when designing manifolds.

MR. BREWER:—When I began experimenting with the lighter fuels, in connection with my original designs of manifold, a satisfactory attempt was made to drain the fuel off in a similar way to that used by Mr. Dorris but, instead of using external pipes, grooves were embodied in the design of the manifold so that if any precipitation occurred, which was actually the case only at night after the engine had cooled and there was a certain condensation in the manifold, the precipitate would run back into

[4] See pp. 269 and 271 of this issue.

the intake-pipe. So far as I could see, these manifolds were always designed with the location of the heated area where it should be. In many designs of manifold one finds that the designer has failed entirely to realize where the precipitation would occur and locates the heating surface in the wrong place. Small modifications in a manifold make all the difference, but that is not often realized.

Another point not generally appreciated is that in the natural condition of an automobile everything is cold; a manifold that will operate perfectly well when it is hot does not operate satisfactorily when cold, and it is extremely difficult to get cold distribution. In designing a manifold I always try to run the whole gamut, just as the user would do, from a cold engine and cold distribution, working onward and eliminating the defects in the hot distribution afterward. Mr. Mock pointed out that separation of the liquid from the airstream in the initial stages is of very great importance. But I think the separation of the liquid in various parts of the manifold in the Dorris design will affect the mixture strength reaching the different cylinders. Separation should occur from the main stream; so, the portion that passes the separator should be homogeneous and remain in that condition under all conditions of absolute pressure.

Much can be done in manifold design by varying the temperature with the absolute pressure; that is not often borne in mind, but it is an interesting point in design. One can heat the vapor to a temperature and a condition where it remains fixed and, after it becomes thoroughly fixed in that condition, one can lower the temperature without getting precipitation.

CHAIRMAN O. C. BERRY:—I wish to add emphasis to Mr. Brewer's point that the place to separate the liquid fuel is at the main stream in the intake manifold, before it has been divided into the different portions going to the various cylinders. This is the only way in which vaporizing the fuel can aid distribution. An over-rich or over-lean gaseous mixture at any cylinder is just as much to be deplored as a poorly distributed wet mixture.

As one makes the mixture lean in striving for greater economy, there are certain bad effects to watch for. The car may run along very well at constant speed, but when one suddenly opens the throttle for acceleration, the engine dies. The reason is that when the throttle is opened suddenly, the air gets ahead of the gasoline and the mixture that reaches the cylinder is temporarily lean. In designing manifolds for heating the liquid portions and vaporizing them, I think we must bear in mind that one of the essential points is to delay this liquid as little as possible. The greater the delay is, the greater the task the carbureter has in overcoming manifold difficulties. We must get the gasoline vaporized as quickly as possible and make the delay as short as possible.

ELEMENTS OF AUTOMOBILE FUEL ECONOMY

BY W. S. JAMES

THE paper analyzes and states the factors affecting the power requirements of cars as rubber-tired vehicles of transportation over roads and the factors affecting the amount of power supplied the car as fuel to produce at the road the power required for transportation. Quantitative values are given wherever possible to indicate the present knowledge of the relation between the factors involved, and the text is interspersed with numerous references, tables, charts and diagrams.

Among other important factors specifically discussed are mixing and vaporization, charge quantity control, the heat of combustion, gas-pressure, transformation loss and power transmission efficiency.

Six appendices contributed by other associates of the Bureau of Standards are included. These are illustrated and treat in detail the subjects of the influence of air and fuel proportions upon engine efficiency and power, the metering characteristics of six stock carbureters, the mechanical efficiency of engines with particular reference to part-load conditions, ignition timing, fuel knock and the relative merits of large slow-speed and small high-speed engines. [Printed in the June, 1921, issue of THE JOURNAL]

THE DISCUSSION

MR. JAMES:—This paper is of an outline character. It is a compilation or analysis of the factors that are involved in automobile fuel economy, arranged somewhat like a filing system. We have attempted to put behind each index card what information we could find, and to state the fact when no information was available.

The process involved in the production of power at the rear-wheel rims from fuel supplied to the engine can be divided into the four main groups of (*a*) the preparation of an explosive mixture of fuel and air, (*b*) the transformation of the chemical energy latent in the explosive mixture into gas pressure, (*c*) the transformation of the gas pressure produced into crankshaft torque and (*d*) the transformation of crankshaft torque to thrust at the road surface. The division lines between the first three items are not definite and can be drawn in several ways.

In commenting upon the portion of the paper dealing with the power requirements of cars, it should be noted that our knowledge of wind-resistance constants is meager, that the rolling resistance of a given car is practically independent of the speed, that the rolling-resistances of various road surfaces are extraordinarily variable and uncertain and that the major portion of the power required on the level when driving at low speed is necessary to overcome rolling resistance and at high speed to overcome wind resistance.

Temperature has been found to have far more effect than pressure on the lean limit of inflammability, which is the one that is of interest when considering fuel economy. When we have learned which mixture will explode, then the fuel and air can be proportioned to give either maximum economy or maximum power, as we desire. In Appendix 1 Mr. Sparrow points out a fact that should be borne in mind by those who conduct dynamometer fuel-economy tests of engines. Very careful work has been done in measuring the power output and the fuel consumption of engines under constant throttle-positions, or else constant manifold-depressions at constant speeds with varying fuel-air ratios. When the brake thermal efficiencies are obtained from this work, the results have been applicable to either conditions of constant manifold-depression or throttle-position. Neither of these conditions is encountered in a car on the road. When driving at say 25 m.p.h. a definite amount of power is required;

if the fuel-air ratio is changed and the car is still driven at 25 m.p.h., the same amount of power will be required. The manifold depression has changed as the mixture has been made leaner, for example, and the power decreases although the manifold depression is the same. To maintain a car speed of 25 m.p.h. the throttle must be opened. Mr. Sparrow has recomputed some of these data to show the ratios of air to fuel that will give maximum economy when delivering constant power at constant speed. The lower curves in Fig. 7 of my paper show that absolute manifold pressure has no effect whatever on the indicated thermal efficiency except at low throttles. The curve for a manifold pressure of 30 cm. (11.81 in.) shows that the engine cannot run on a mixture leaner than about a 13½ to 1 ratio; therefore, it becomes evident that, in general, the mixture ratio for maximum economy is the leanest mixture on which an engine will run regularly.

Fig. 1 of my paper shows the effect of the pressure of exhaust gas on the maximum mixture-ratio that can be used in an engine. The data for the case of the valve-in-head engine were taken from published data on the maximum air-fuel ratio at which the engine would run at various manifold depressions, from 300 to 650 mm. (11.81 to 25.59 in.), and plotted against the percentage of the weight of inert gases of the total weight of the cylinder contents. The general indication of the curve is that as the weight of inert gases increases the mixture ratio at which the engine will run becomes smaller and smaller. This is one of the limitations of a throttling method of charge control.

Figs. 2 and 3 of my paper indicate the difficulty of the problem of mixing the fuel and the air. If the cube representing the liquid has a unit volume, the fuel in the vapor state has a volume of about 200 and the air a volume of about 8000. Of this air only about 25 per cent is oxygen. The residual products of combustion also are added to the air. Fig. 2 represents conditions at full-load and Fig. 3 the conditions at about 20-per cent load. All this mixing must take place in a very short length of time. The problem of fuel and air mixing probably is the most important one upon which work could be done to increase the fuel economy of Otto-cycle engines.

Of the two possible methods of accomplishing mixing, vaporization and atomization, the major emphasis has been placed on vaporization, but there are great possibilities in atomization. Mr. Horning has stated that when liquid fuel is admitted to the cylinder, it never burns. I believe that is not true, because there is a large amount of heat available within the cylinder itself for vaporization. First, there is enough heat generated in compressing the charge to vaporize practically all of the fuel; second, from full-load to part-load and over the entire range of speeds covered, it will be found that there is from an equal amount to 100 per cent more heat available in residual exhaust gas to vaporize the entire weight of fuel entering. These facts were indicated last year in a paper we presented on hot-spots[5] showing that, at constant speed and load, it made no difference in fuel economy how much or how little the intake air or the manifold was heated. These results can point only to the fact that the fuel was vaporized somewhere between the time it entered the intake port and the time it was fired. We knew at that time that liquid gasoline was entering the cylinders when the air and the manifold were unheated.

Regarding charge quantity control, I wish to say emphatically that the pumping losses in the Otto-cycle engine are not as great as they have often been stated to be. The decrease in economy is about 20 per cent at 20-per cent load.

In the transformation of the chemical energy of the fuel, which we will assume to be in the cylinders and thoroughly mixed, into gas pressure in an engine cylinder, the two factors involved are the increase of pressure due to an increase of temperature and an increase of pressure due to an increase in specific volume.

It has been shown definitely that the ignition of a charge is unaffected by the kind of spark used, as long as there is a proper mixture. It has not been shown, however, that the character of the spark has no effect if there is not a proper mixture. We have been able to show very recently that the characteristic of a spark, when the conditions of firing are poor, has a very marked effect. From what Mr. Sparrow has written in Appendix 4 it is clear from Fig. 17 of my paper that the change in spark-advance necessary for change in load is of much more importance than the change in spark-advance necessary for a change in speed. The increase in spark-advance necessary with reduced load is possibly due to the presence of a greater percentage of inert gases.

We know practically nothing about the rate of heat loss from the gases during combustion, and there is very little reliable information on the rate at which energy is liberated, although in all probability that is one of the most important outstanding problems today, because detonation is involved in it. Fig. 4 of my paper gives two curves, computed from indicator cards, showing the rate at which energy is evolved in a cylinder. The one on the left is for commercial fuel, and the other for aviation fuel. All I can say about these is that they are different; we do not know why.

Appendix 5, by Dr. Dickinson, is an excellent summary of what we do and do not know about detonation. He lists the things that we think affect it, and states three theories as to why it happens. Regarding the three theories, Dr. Dickinson has summarized the situation very well in the last paragraph of Appendix 5.

With regard to the transformation of gas pressures into crankshaft torque, there are four sources of loss in a gas-pressure crankshaft-torque transformation-mechanism that refer directly to the mechanism itself. The air-cycle efficiency as commonly used gives the value for loss from incomplete expansion very correctly, but nothing more.

The next most important losses are those due to charging the cylinder and to mechanical friction. The top curve in Fig. 16, in Appendix 3, shows the percentage of loss due to pumping; it is about 20 per cent at about 20 per cent of full load. When this work was being done we had an idea that we could eliminate all pumping losses by putting in exhaust gas; but we found that the pumping loss decreased slightly as soon as we added exhaust gas, and that the air-fuel ratio at which the engine would run was decreased at the same time. The decrease in economy due to the necessity of running with a richer mixture was four or five times the gain from the decreased pumping-loss.

The importance of jacket-water temperature on friction losses is indicated in Fig. 15 of my paper. It is often thought that if the cylinder-heads are removed and the friction horsepower measured, and the cylinder-heads are replaced and the friction horsepower measured again, the difference between the two is the pumping loss. Unfortunately, this is not true. The error is probably due to a difference in mechanical friction under load. That is disheartening, because it is convenient to add the brake

[5] See THE JOURNAL, August, 1920, p. 131.

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horsepower to the friction horsepower and get indicated horsepower. The values obtained by this method are near the correct values and are probably all right for general purposes, but it has never been proved absolutely that the sum of the brake and friction powers gives the indicated power. However, what I have mentioned is the only evidence we have ever seen that this is not true.

In Appendix 6, on the relative merits of large slow-speed and small high-speed engines, Mr. Sparrow has taken the power required to drive a car on a level road as given in A. L. Nelson's paper on the Fuel Problem in Relation to Engineering Viewpoint,[6] and the brake horsepower developed for an engine that we have at the Bureau of Standards. The brake-horsepower curve is given in the second curve, marked *X*, in Fig. 19 of my paper, and it has been assumed that the brake horsepower of the engine has been increased 50 per cent by the addition of two cylinders; in other words, comparing four and six-cylinder engines of the same bore and stroke. It has been assumed also, as shown in the two lower curves, that the friction power of the larger engine is 1½ times that of the smaller engine.

In Fig. 20 of my paper the power curves given in Fig. 19 have been put on the basis of miles per hour. Rear-axle ratios of 3 to 1 and 4½ to 1 have been assumed for the larger and the smaller engines respectively. The power curves show practically no difference in performance.

In Fig. 21 of my paper Mr. Sparrow has computed the fuel consumption in pounds per brake horsepower-hour for the two engines and also the miles per gallon. In computing the brake horsepower for the larger engine he has made the assumption that the friction power changes with the throttle position, in accordance with the lower curve in Fig. 21. When the results of these computations are put on the basis of miles per gallon, there is about a 7½-per cent difference in favor of the larger slower-speed engine. But of course the weight will be increased when a larger engine is used, and it has been assumed that the engine weight must be increased 50 per cent. This results in an increase of the total car weight of about 7½ cent and we get practically equal performance in the two cases if everything is done to favor the small high-speed engine. As Mr. Sparrow states, this analysis does not prove the superiority of either type of engine for every case, but it raises a point which every builder of small high-speed engines would do well to investigate.

There remain only the losses through the drive system. The universal-joint efficiencies are very high, particularly at medium powers. The gearbox efficiencies vary from 70 to 90, and the rear-axle efficiencies from 70 to 98 per cent. Improvements in all those possibly can be made, but they are affected so much by the type of lubrication that it is very difficult to draw any definite conclusions.

One point that I would like to make is that I believe the automotive industry has neglected the accessory manufacturer. We have 10,000,000 or more cars on the road today, and the car builder seems to lose all interest in his product after it is out of the factory, particularly when it is two years old. But these are the cars that are using up the fuel. It probably is possible to increase fuel economy very markedly by changing the intake system. There are many devices on the market for doing this; some of them are good, and others are bad. Why do not the car builders go over the list of devices that are available? They know what their cars can do, and they can recommend devices that will give car users increased service.

THOMAS MIDGLEY, JR.:—I consider Appendix 5, by Dr. Dickinson, as a truly remarkable summation of the physical characteristics affecting detonation and by far the most thorough presentation of facts upon this subject that has been presented. Whereas Dr. Dickinson has proved unquestionably the existence of the wave-front by an excellent mathematical treatise on the subject, I simply wish to call attention to a visualization that is possible on this point. In the several indicator-cards which we have presented to the Society a very definite rapid rise of pressure and a corresponding quick decrease evidenced the knock. The excellent work of the Bureau of Standards has confirmed this rapid rise and drop. Dr. Dickinson has proved beyond question that the rapid rise is of such a mathematical value that it could not be caused by a uniform pressure of such a value throughout the combustion-chamber. I wish to point out that, were this pressure rise caused by a uniform pressure in the combustion-space, we would then have the expansion-line starting from the peak of this curve and not have a rapid drop in pressure. In other words, while the rapid rise in pressure might be explained by a uniform pressure throughout the combustion-chamber in theory, I defy the adherents of such a theory to explain how this pressure falls so rapidly.

In reply to Dr. Dickinson's remarks concerning the uniformity of distribution of this detonation wave, giving no localized effect, I refer to the paper on the Nature of Flame Movement in a Closed Cylinder, by C. A. Woodbury, H. A. Lewis and A. T. Canby.[7] I believe that the proper interpretation of their sulphuric-ether photographs was not made. The photograph of the wave front passing down a bomb was made on sulphuric ether, which is one of the violent knocking fuels. It was started with a spark-plug at one end and proceeded throughout the bomb to a uniform bright flash. It is this bright flash that we believe contains the wave-front traveling at a high rate of speed, the striking of which causes the sound and the chemistry of which we believe to be the preferential burning of hydrogen. We think this is the greatest limiting factor of thermal efficiency. It is evident that this bright flash passed back fully as rapidly through the burned mixture as it did through the unburned or partially burned mixture, and I feel fairly certain that this explains what Dr. Dickinson has observed as the uniformity of temperature rises and pressure effects.

DETERMINING DEW-POINT OF GASOLINE

PROFESSOR WILSON:—I will sketch briefly some of the work that we have been doing at the Massachusetts Institute of Technology to determine definitely the dew-point of gasoline and kerosene when mixed with air in various proportions.[8] In developing a carbureter or manifold with special arrangements for heating the mixture to secure complete vaporization, it is especially desirable to know the minimium temperature to which the mixture would theoretically need to be heated. If I should say that 100 deg. fahr. would be proper if one had a perfect manifold, then everyone would realize that volumetric efficiency is lost by heating the mixture to 175 deg. cent. (347 deg. fahr.), which may seem necessary to get complete vaporization in a given manifold. That is exactly the case for present-day gasoline. It is rather

[6] See THE JOURNAL, February, 1921, p. 101.

[7] See THE JOURNAL, March, 1921, p. 209.

[8] This subject has since been discussed in more detail in an article entitled Condensation Temperatures of Gasoline-Air and Kerosene-Air Mixtures, by Robert E. Wilson and Daniel P. Barnard, IV, which will be published in an early issue of THE JOURNAL.

GASOLINE AND OTHER

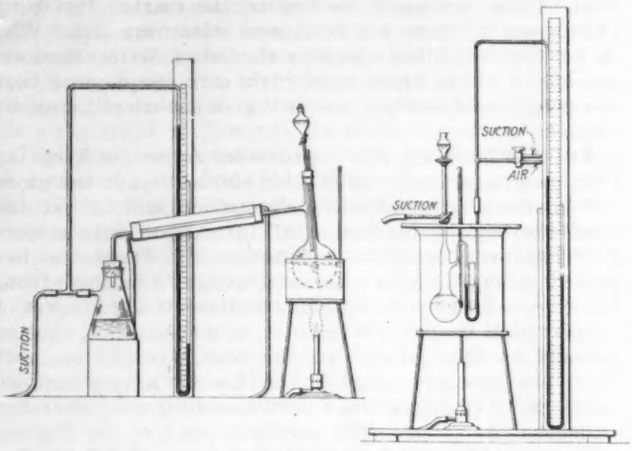

FIG. 7—APPARATUS AT THE LEFT FOR THE PREPARATION OF EQUILIBRIUM SOLUTIONS USED IN DEW-POINT CALCULATIONS AND AT THE RIGHT THAT EMPLOYED FOR DETERMINING THE VAPOR PRESSURE

surprising that these facts have not been brought to the attention of automotive engineers.

In developing distribution systems we are limited partly by the carrying-capacity of the air, which is surprisingly high, and partly by too slow a rate of vaporzation. If we can separate these two factors into their component parts and determine what part of the difficulty is due to the inherent limitations of the fuel and the carrying-capacity of the air, and what is due merely to the mechanical difficulty of getting the heat of vaporization into the unvaporized drops with sufficient rapidity, we will be able to focus our attention on the right method of progress. This will also give us a definite method of determining the efficiency of a given hot-spot manifold, simply by determining the carrying-capacity of the air for the particular fuel on which the experiments were made, and finding what temperature actually must be reached in a given manifold to obtain complete vaporization.

Unfortunately, however, there has been no satisfactory method of measuring the dew-point of a mixture of gasoline and air. The simple methods which are used for pure compounds are not at all applicable in this case, because gasoline is a mixture of compounds of widely different volatility. One might ask why we do not measure the vapor pressure of gasoline, since that is the method of determining the dew-point of a pure compound. The trouble is that the liquid which first separates out from a completely vaporized mixture does not have the same composition as the gasoline as a whole, nor does it have the same composition as the last 10 per cent which distills over, as was tentatively assumed by Frank A. Howard in the paper that he presented at the 1921 Annual Meeting.[9]

If, however, we could get some of the mixture that first separates out of the airstream on cooling, and measure its vapor pressure, it would be a comparatively simple matter to calculate the dew-points. It is difficult to get enough of that which first separates out and be sure it represents the equilibrium between the vapor and the first drop of liquid that comes out. The method which we have developed for accomplishing this involves the use of a distillaton flask, such as is shown at the left of Fig. 7. This is filled to a certain level with the fuel in question and that level is maintained accurately by observing a hook-gage that just comes to the surface. The flask is put into an oil-bath, the fuel in question is poured into the flask through the upper reservoir and distillation is begun. A thermometer records the temperature of the liquid boiling in the flask.

If a given sample of gasoline is used, it will start boiling at the initial boiling-point of that sample, but we know that the vapor that distills off first is more volatile than the original substance and, therefore, the liquid that stays behind is less volatile. We continue to add fresh fuel to keep the level constant, and the vapor passing out is still richer in the lighter ends; so, we concentrate the less volatile portion in the flask. While we are doing that the boiling-point continually rises, as shown by the thermometer in the flask. Eventually, however, we reach a point where the temperature remains absolutly stationary. We continue the process for 30 min. more to be certain that we have a condition of equilibrium. At that time the composition of the vapor that leaves the flask must be exactly the same as the composition of the liquid that comes in, because input must equal output when steady conditions have been established. Therefore, the liquid in the flask accurately represents the liquid that is in equilibrium with the completely vaporized fuel, or that which would be condensed out first on cooling the air mixture, and that is exactly what we want. Then we remove that from the flask and measure its vapor pressure.

Figs. 8 and 9 show different forms of the distillation curves of the three fuels used; Socony gasoline, Socony kerosene and an artificial high-end-point gasoline which we made by mixing 100 parts of gasoline with 25 parts of the first half of the kerosene fraction. Fig. 9 shows most clearly the comparison of the composition of the original fuel and of the equilibrium solution obtained by the method that I have described. It will be noted that the equilibrium solution contains not only some of the high ends, but some of the lower ends. As a matter of fact, the average boiling-point of all of the equilibrium solutions comes at about the 85 per cent point in the distillation of the original fuel.

I will not describe the method that we used to measure the vapor pressure of the equilibrium solutions, but we obtained very accurate data on all three fuels, using the apparatus shown at the right of Fig. 7, from which we are able to calculate the temperature of initial condensation as a function of the richness of mixture and of the total pressure. Of course, when we are working in vacuum or under compression in the cylinder, we have other than a pressure of 1 atmosphere.

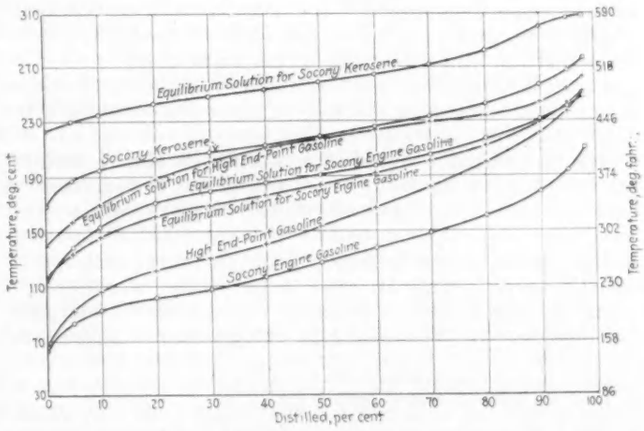

FIG. 8—DISTILLATION CURVES FOR FUELS AND THEIR EQUILIBRIUM SOLUTIONS

[9] See THE JOURNAL, February, 1921, p. 145.

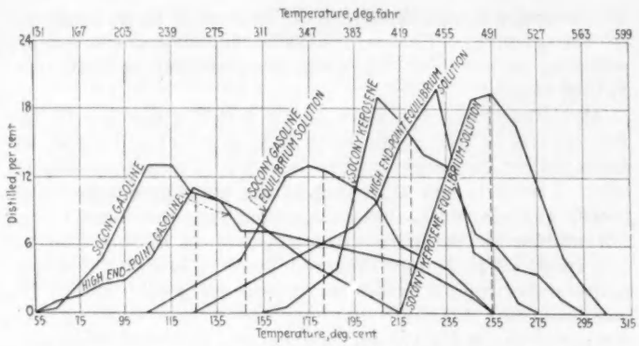

FIG. 9—DIFFERENTIAL DISTILLATION CURVES FOR THE FUELS SHOWN IN FIG. 8 AND THEIR EQUILIBRIUM SOLUTIONS

Fig. 10 shows the complete results on Socony kerosene. It will be noted that for a 15 to 1 mixture at a pressure of 1 atmosphere, 104 deg. cent. (219 deg. fahr.) is the point at which condensation begins. Fig. 11 shows the results for all three fuels, and not only the temperatures at which condensation begins, which values we have determined accurately, but also approximate values for partial-condensation temperature. It should be remembered that these results are strictly true only in case a condition of equilibrium is attained. It shows what can be done if our mechanical contrivances are perfect. Fig. 11 shows that, under the specified condition, the Socony kerosene has a dew-point of 104 deg. cent. (219 deg. fahr.), the artificial high-end-point gasoline a dew-point of 57 deg. cent. (135 deg. fahr.) and the ordinary gasoline a dew-point of 35 deg. cent. (95 deg. fahr.). In other words, in the case of that particular gasoline, which may be somewhat better than the ordinary, every degree we have to heat our mixture above 95 deg. fahr. is because our mechanical contrivances are not sufficiently good. It shows the great importance of developing even further the hot-spot manifold proposition, and that the fuel itself has no inherent limitations to make it particularly difficult to obtain complete vaporization.

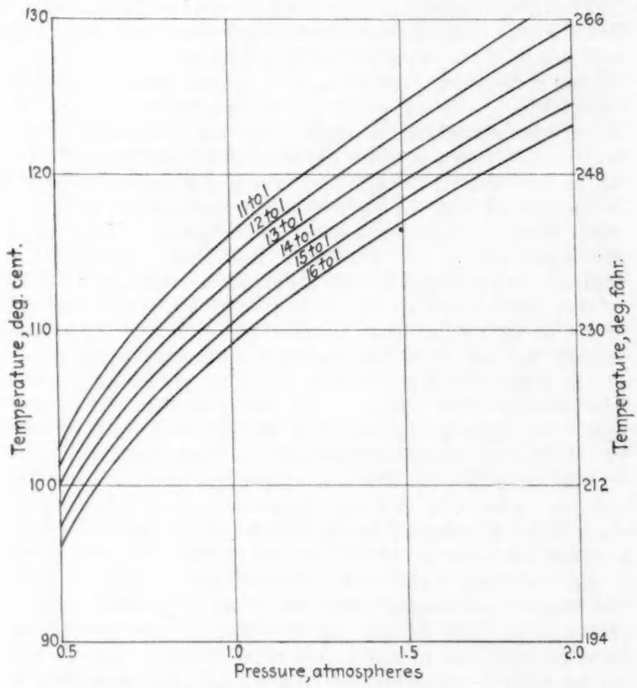

FIG. 10—INITIAL-CONDENSATION TEMPERATURES OF THE KEROSENE-AIR MIXTURE

I will show also the essential results which we have obtained as to the amount of heat required to vaporize the fuels. Fig. 12 shows a total heat curve for liquid kerosene. With regard to what Mr. Horning has said, I wish to point out that while the heat of vaporization of kerosene is less, that is only a small part of the heat that we must put into the kerosene to get it into the air-stream, because we must put specific heat in even though we have liquid kerosene. The heat of vaporization of kerosene is very low, so that the specific heat becomes an important factor. This comes in through heating up a liquid without getting vaporization. In a pure compound the curve rises sharply because it all boils at the same temperature; but kerosene only boils off gradually, so the curve rises gradually. The differences between the extension of the lower line and the two higher ones repre-

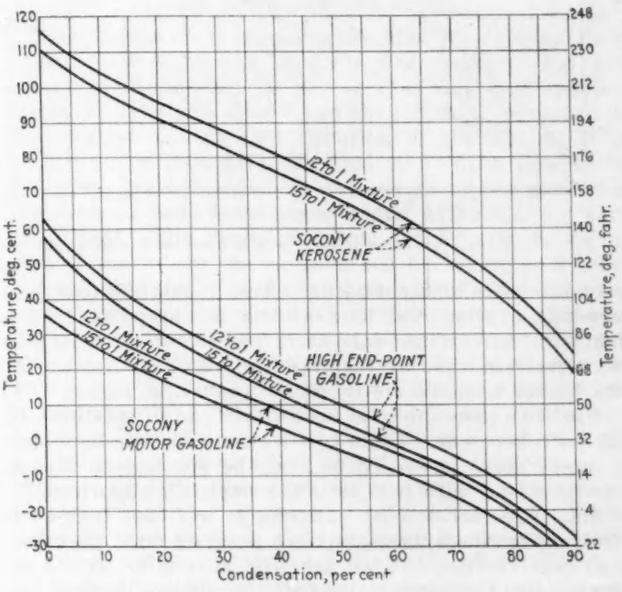

FIG. 11—TEMPERATURES OF PARTIAL CONDENSATION OF AIR-FUEL MIXTURES AT A PRESSURE OF 1 ATMOSPHERE

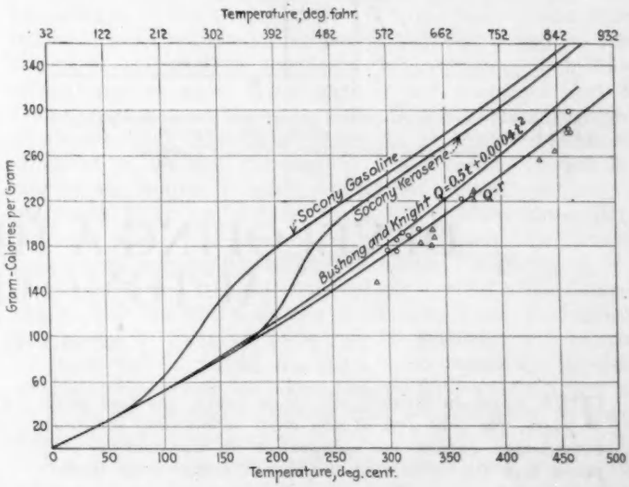

FIG. 12—TOTAL SENSIBLE HEATS OF KEROSENE AND GASOLINE

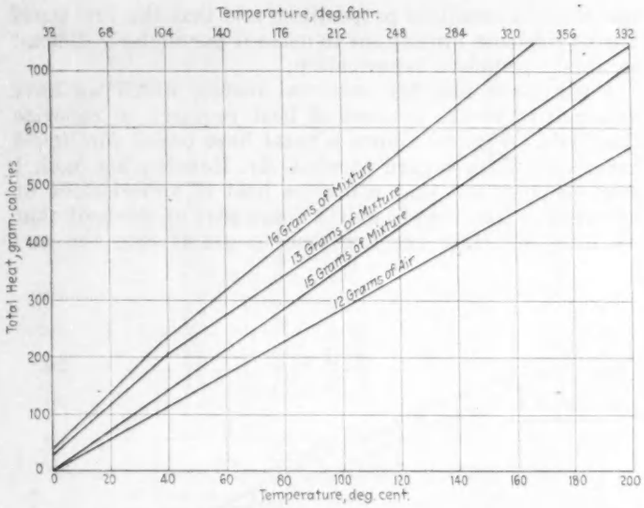

FIG. 13—TOTAL SENSIBLE HEATS OF A KEROSENE-AIR MIXTURE

sent the heats of vaporization. That is slightly less than one-half of the total heat at the boiling-point. As a matter of fact, it does take more heat to get kerosene into an airstream than is required for gasoline, because of the higher temperature to which it must be heated.

Fig. 13 shows the total heat of air and of mixtures of air with kerosene. From this we can calculate how high a temperature is needed to heat the gasoline so that it can be mixed with cold air and completely vaporized.

MR. GERNANDT:—We advocates of the high-compression engine appreciate what is being done on manifold construction, but we ask why an engine should be complicated with a miniature distillery when the fuel can be burned without distilling it, just as it is pumped out of the ground. The complication is very slight in developing an engine to burn the heavier fuels without distilling them.

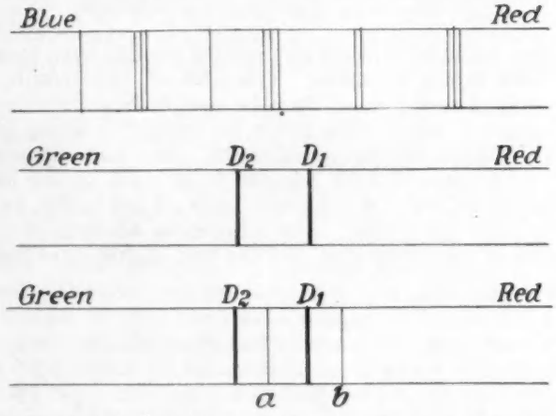

FIG. 14—DIAGRAM SHOWING HOW THE SPECTROSCOPE CAN BE EMPLOYED AS AN INDICATOR OF CONDITIONS IN AN INTERNAL-COMBUSTION ENGINE CYLINDER

MR. BREWER:—We have given much attention to the fine details of fuel combustion but, in general, I think we have rather lost sight of the losses in the automobile itself. I wish to call attention to the enormous amount of power that is dissipated in accelerating the mass of an automobile including its unsprung weight as it passes on the road. Mr. James referred to this briefly. I made many experiments some years ago on power loss. On one racetrack I found that the power loss even on one circuit of the track varied enormously, and that from day to day one never could get two readings that were alike. In Mr. James' paper are given some figures for the rolling resistance of cars, among them a Benz. Some of this is referred to in Wimperis' paper and, as a matter of fact, I made the experiments on the Benz, and they are the highest recorded speeds with the Wimperis accelerometer that have ever been made. I made observations at a car-speed of 120 m.p.h.

SPECTROSCOPIC POSSIBILITIES

MR. MIDGLEY:—Because of a statement I made at the 1921 Annual Meeting with regard to the spectroscope, I wish to say that we have continued that work, and that we cannot get a trace of the green band in the spectrum. Some interesting spectroscopic possibilities have developed in the recent work. In Appendix 5 to Mr. James' paper the statement is made that the pressures in the wave-front reach a limit between 5000 and 7000 lb. per sq. in. and that it is very doubtful if any indicator in use is capable of responding to such instantaneous pressure, other than to register a kick, so to speak. We have in the spectroscope an indicator that has been able to indicate the position of the atoms in a molecule, the size of the positive nucleus at the center of a molecule and the speed at which heavenly bodies approach us. These are speeds that we could not measure with any speedometer. If the light coming out of a cylinder passes through a spectroscope, the spectroscope divides that light into band-like colors as indicated in the upper portion of Fig. 14. Different elements give definite, positive lines. The middle drawing of Fig. 14 shows the yellow lines of sodium, called the *D* lines, magnified. The position of these lines is affected by pressure, although it requires a great pressure to move them very far. The lines at *a* and *b* in the diagram at the bottom of Fig. 14 show how these lines would vary from the originals under a pressure of 4500 lb. per sq. in. So, in this device we have an indicator of extremely small inertia that we are trying now to make use of to measure this pressure in the wave-front exactly.

DEVELOPING A HIGH-COMPRESSION AUTOMOTIVE ENGINE

BY FRED C. ZIESENHEIM

THE paper is divided into three parts; the fuel problem, the selection of the most economical internal-combustion engine for adaptation to automotive purposes and the details of the development work undertaken.

After stating the fuel problem, inclusive of production, volatility and price charts, the methods of increasing the engine-fuel supply, the characteristics of present engine fuels and general considerations regarding the selection and adaptation of the most economical engine are discussed. Classifying internal-combustion engines as being of low, medium or high compression, the essen-

tial factors, advantages and disadvantages of each class are commented upon in detail.

High-compression engines are classified, as to their method of injecting the fuel into the combustion-chamber, into the three general classes of air, gas-pressure and mechanical injection. These are described and analyzed at length, numerous charts and diagrams being included, and a lengthy summary of all the essential factors thus far considered follows.

The development work on mechanical injection that was done in the laboratory of the Carnegie Institute of Technology, Pittsburgh, is illustrated and described in detail. The two methods, variable-pressure and constant-pressure, are discussed separately at length. [Printed in the July, 1921, issue of THE JOURNAL]

THE DISCUSSION

F. C. ZIESENHEIM:—Supplementing my paper, the principal disadvantage of the Diesel engine for development in small units is the air-compressor. The air for injection is at a pressure of from 200 to 600 lb. per sq. in. higher than the compression pressure, which is about 500 lb. per sq. in. and is sufficient to cause autoignition of the injected fuel. To pump up a small quantity of air to a pressure of 800 to 1200 lb. per sq. in. requires an air-compressor of considerable size and an air-compressor is a mean piece of apparatus at best; most of the trouble that is encountered in the operation of Diesel engines can be attributed to it. Consistent progress is being made in eliminating the troubles, but many of the conditions for trouble still exist; for instance, in the lubrication of the Diesel-engine air-compressor, if too much oil is used, the air receivers will be charged with an oil vapor that is explosive and often causes considerable damage.

The statements in my paper in regard to the Pittsburgh Filter & Engineering Co.'s Brons-Hvid engine were based on information obtained during the period of development. This company has since informed me that the troubles mentioned do not exist in the present engine.

The Steinbecker engine is a German gas-pressure-injection engine. It is rather odd, in that connection, that the Germans stated emphatically that the Diesel engine was absolutely the only form of high-compression engine that was possible; but, as soon as Steinbecker announced his engine, they immediately agreed that other types could be built and said that they had constructed one.

Another point in regard to the Diesel engine is that the expansion of the injection air causes a refrigeration effect. This requires carrying the compression to a higher pressure than is necessary in a mechanical-injection engine. Referring to Fig. 4 of my paper, which gives the air temperatures for different final compression-pressures, for 350 lb. per sq. in. compression we get about as low a temperature for ignition as is permissible for starting. Of course, after the engine has warmed up and is operating, we can use a lower compression-pressure. Some engines use other means of securing heat when starting; the engine then runs on autoignition.

There are two types of mechanical-injection engines. One uses the variable-pressure method, in which the pump pressure opens the valve; in the other, the fuel is maintained at a constant pressure and the injection valve is lifted mechanically by a cam.

My reason for selecting the constant-pressure method of fuel injection in preference to the variable-pressure method, strictly for small units, is that with the latter the injection of a very small quantity of fuel is rather difficult. We may be able to measure the fuel definitely at the pump, but to inject that particular quantity into the combustion-chamber is another matter. A very small leakage from the fuel system will amount to more than the quantity of fuel one is trying to inject, even on full load.

A constant-pressure fuel-valve is shown at the center in Fig. 11 of my paper. The fuel builds up under the differential plunger, but the lift spring shown at the top is sufficient to keep the valve closed until the cam lever lifts the valve spindle and permits injection of the fuel.

ALCOHOL AND SHALE OIL

MR. MIDGLEY:—I agree with Mr. Ziesenheim thoroughly that we cannot hope for coal products that will exceed approximately 20 per cent of our fuel requirements in light oils, benzol and the like but, in regard to his analysis of the fuel situation of the future, it is rather a new thought to me that to produce alcohol the use of as much heat as we can get from the alcohol is required. I have made some alcohol without using very much heat. The alcohol situation and its relation to the fuel of the future can be described by saying that from our cellulose waste products on the farm such as straw, corn-stalks, corn-cobs and all similar sorts of material that are virtually thrown away at present, we can get, by present known methods, enough alcohol to run our automotive equipment in the United States. The process is a process of hydrolysis, fermentation and distillation. However, the yield is only about 10 per cent and the alcohol would cost us about $2 per gal. I think that it is the cost of production that makes alcohol scarce, rather than the heat that is required to make alcohol. In the laboratory we can get as high as an 80 per cent yield, and it is not at all outside of the realm of possibility to increase the yields in commercial practice to such an extent that alcohol will compete with gasoline and we can leave some petroleum in the ground.

With reference to the shale-oil situation, I do not deny that it may be possible to produce shale oil that will compare favorably with present crude oils, but the best shale oil we can produce with our present knowledge is worse than the worst Mexican crude oil. There is very little light stuff in it. It is very difficult to refine it and obtain a fuel that the public will approve.

AUTOMOTIVE-OIL ENGINE POSSIBILITIES

MR. GIBSON:—I am very glad that Mr. Ziesenheim is looking a long way ahead but, in discussing the disadvantages of the Diesel engine, I think that it would be better not to emphasize so much but put it up to the talent of automotive engineers to overcome such disadvantages as exist. First, it is not essential that a Diesel engine be so heavy because of its high compression. That is simply a popular thought. When we come to think of it, we are starting with a pressure of 500 lb. per sq. in., which, roughly, we do not exceed, we merely maintain it in the Diesel cycle. We know from Mr. Horning and other supporters of the detonation theory that we get a much higher pressure than 500 lb. per sq. in. in the ordinary internal-combustion engine. The Diesel engine has no shock at all; it is free from detonation troubles. If, then, we have only to deal with a pressure of about 500 lb. per sq. in., there is no reason the Diesel-engine cycle cannot be taken care of with engines just as light as we use today, except that a little more flywheel effect might be necessary.

Mr. Ziesenheim mentioned that the Diesel engine requires a high air-pressure in storage tanks, which is very dangerous. That is true as we know the matter at pres-

ent, but it is not true in regard to a proposed automotive engine. The high-pressure storage is for the purpose of starting the engine, but I have actually started a small Diesel engine without any pressure. It is a perfectly simple matter. We put a clutch between the flywheel and the crankshaft and rotated the flywheel up to a fairly high speed by some means such as an electric starter. The required energy for starting is stored in the flywheel and so long as a reasonably positive clutch is used between the crankshaft and the flywheel it is all right; I have done this in a perfectly satisfactory manner. If we adopt the attitude that such things can be done, I think we will progress more rapidly than if we assume too much that they cannot be done.

MR. GERNANDT:—There are five considerations to be dealt with in producing an automotive type of engine; the small high-speed engine, the metering of small quantities of fuel, the weight, the speed range and control and the type of fuel to be used. This subject has been my hobby for a number of years, in which I have built several types of high-compression oil-engine. I developed one at a time when weight was of secondary consideration, the idea being mainly to prove that small quantities of fuel can be metered and that the small type of engine can be built. Since then I developed a small engine of 2¾-in. bore. The cylinder-head was 5/16 in., the cylinder wall ¼ in., the piston-head 3/16 in. and the piston skirt 5/64-in. thick. The crankshaft was of liberal size, comparable with that of the standard automobile engine, and the flywheel weighed 94 lb. We were able to burn gasoline, kerosene, distillate, alcohol and fuel oil in this engine, without any change or adjustment. It was impossible to tell exactly what fuel was being used when it was running. The speed range was from 225 to 2250 r.p.m. and there was no misfiring whatever. The engine being of the two-cycle type, the matter of idling is worth considering. This engine has convinced me absolutely that the automobile engine can be built to use high-compression and oil as fuel.

MR. MOCK:—How many cylinders had the engine?

MR. GERNANDT:—It was a single-cylinder engine.

MR. MOCK:—How did you control the load?

MR. GERNANDT:—Merely by controlling the amount of fuel used.

MR. BREWER:—Has a multi-cylinder Hvid engine ever been built that gives equal power in each cylinder?

MR. ZIESENHEIM:—I think the engine of the Pittsburgh Filter & Engineering Co. is about the cleanest-cut four-cylinder Hvid engine that has been produced in this country. I think the results from it are comparable with those of a Diesel engine, so far as carrying full load on each cylinder is concerned. The Western Machinery Co. builds a gas-pressure-injection engine that is considered very satisfactory; the company has been in business for a number of years and there is no question that the engine can carry a full load uniformly distributed. I know that the Pittsburgh company's engine does deliver uniform power from each cylinder.

MR. BREWER:—That is a small engine, is it not?

MR. ZIESENHEIM:—It is a 100-hp. engine. Another small four-cylinder engine of the Hvid cycle is the Quayle engine built by the Commonwealth Motors Co., of Chicago, which has produced a number of them. The engine operates satisfactorily, but I do not know how well it distributes its load. The engines have been sold for driving generators; to drive a generator, unless uniform power is obtained from all of the cylinders, the engine would not be at all satisfactory.

MR. BREWER:—The Hvid engines on the oil-engined auxiliaries of the Shipping Board are mostly of the four-cylinder type. I believe they have great trouble in keeping the adjustment such that the four cylinders generate power equally. This is because the Hvid-engine fuel-control is extremely delicate. It is likely to become choked unless kept scrupulously clean.

MR. ZIESENHEIM:—One will never find two engineers who have the same mind as to how the Hvid engine operates. It is automatic. There are numerous influential factors, and each one takes its turn at being the dominant one. Any man who can get uniform results in operating a dozen different Hvid engines is a wonder. The principal disadvantage of the Hvid engine is that it is automatic and one cannot control it. The operation cycle cannot be controlled at all; moreover, if one changes the load conditions or the fuel, one must start all over; all that one has done in developing the engine seems not to have given any data that can be used to meet the changed conditions.

CHAIRMAN BERRY:—We all appreciate the fine qualities of the Diesel and the semi-Diesel engines and know that there is a definite field in which they will I think predominate. I feel, however, that the Otto-cycle-engine advocate should not be discouraged. Probably, in the ultimate solution of the engine problem, the dominant number of engines will operate on the Otto cycle.

The ultimate solution of the engine problem must be that producing the greatest amount of benefit from the petroleum that we have. We always must have a petroleum lubricant, because we know no substitute that can take any large part in replacing it. A considerable proportion of petroleum must be fractionated. A large part of the fractions will be gasoline and kerosene and we will use them in the Otto-cycle engine. In spite of the literature to the contrary, I feel that the thermal efficiency of the Otto-cycle engine, based on brake horsepower and considering the whole powerplant, will be just about as high as it is possible to get from the Diesel engine when the whole powerplant, including all the auxiliaries, is considered.

MILEAGE INCREASE AND ANTI-KNOCK MATERIALS

MR. MIDGLEY:—I believe that the greatest claim the Diesel-type or high-compression engine has for consideration is its high thermal efficiency. We can get just as high thermal efficiency from Otto-cycle engines if we increase the compression. I recently ran a 7 to 1 compression engine. The pressure was increased merely by decreasing the clearance volume by using longer, or higher, pistons. The comparative economies are shown in Table 2.

TABLE 2—COMPARATIVE FUEL ECONOMIES OF 4.1 TO 1 AND 7.0 TO 1 COMPRESSION ENGINES

Compression ratio	4.1 to 1	7.0 to 1
Fuel Economy at Full Load, lb. per hp-hr.	0.58	0.46
Fuel Economy at One-Quarter Load, lb. per hp-hr.	1.00	0.68
Relative Fuel Consumption when Idling	2	1

In addition, we have an increase in torque of 27 per cent, which can be transferred back and utilized as fuel economy on the road by decreasing the gear-ratio in the rear-axle. The sum total of these results is an 80-per cent increase in mileage. The question is simply how to get that 7 to 1 compression-ratio engine running on ordinary gasoline without having a bad cylinder knock. Since the above statement was made, road tests have proved the

80 per cent mileage-increase calculation to be low; it is more nearly a 125-per cent increase.

Table 3 is a comparison of the relative strengths of the different anti-knock materials. We have included water as an anti-knock material, although it is not truly one; almost everyone is familiar with water injection and can get an idea of the strength. Water takes 200 volumes compared to 1 volume of di-ethyl telluride.

TABLE 3—APPROXIMATE QUANTITIES OF VARIOUS ANTI-KNOCK MATERIALS REQUIRED TO GIVE THE SAME EFFECT

Substance	Volume	Weight	Molecules
Water	200.0	145	1500.0
Ethyl Iodide	35.0	50	60.0
Ortho-Toluidine	20.0	14	24.0
Iodine	2.0	7	5.0
Di-ethyl Selenide	2.5	2	2.5
Di-ethyl Telluride	1.0	1	1.0

CHAIRMAN BERRY:—Mr. Midgley brings out exactly the point that I wanted to have made. I feel that the Otto-cycle engine is capable of developing about the same efficiency as the Diesel, and it has the advantage of simplicity as well as a very much higher state of development at present.

DR. H. C. DICKINSON:—I wish to call attention to Fig. 1 of Mr. Ziesenheim's paper, which illustrates the distribution of the various components of petroleum. What we are interested in as an ultimate matter is getting the maximum of efficient transportation from the amount of fuel that is available. As automotive engineers, perhaps you are inclined to look at this figure and say that we are tapping 25 per cent of the total petroleum resources and that we are not getting hold of 75 per cent of them. Why should we not have the remainder? There are other sides to this question which must be considered. The use of fuel oil in marine transportation is only coming to be recognized in its true light of the saving in cargo space and increase in overall efficiency. Even the burning of fuel oil under boilers, which is certainly an inefficient use of our resources, is so much more efficient than burning coal that probably the shipping interests could afford to pay at present prices at least $10 per bbl. for crude oil. This all goes to show that, whatever happens, the automotive industry cannot look forward to absorbing all of the prospective petroleum supply by any means, because other economic interests can utilize it and can afford to pay as high or perhaps higher prices for it. Therefore, I believe that Mr. Midgley's discussion on the availability of alcohol is very much to the point. If we are to continue to operate automotive appliances on the present basis, we must find fuels for them, and there are two possible solutions. We may develop engines that will use a greater variety of fuel, which is, we all admit, a very important thing to do. No one wants to minimize its importance, but we may also develop fuels that can be used in the present type of engine. The ultimate solution should be the one of maximum efficiency. If the Diesel-engine designer can turn out an engine that competes favorably with the present Otto-cycle engine or with a more highly developed form, of this type he will get the business. The question of available fuel supply is perhaps not as simple as it appears.

MR. GIBSON:—All we are concerned with, I think, in comparing the possibilities of the Diesel and the Otto-cycle engine, is that we cannot utilize an engine that will for some time to come run at practically only one speed. I feel that the Diesel engine has a wide enough field in agricultural tractor work, or truck work, perhaps, but for the millions of automobiles that we are running now the ordinary man will not approve the Diesel engine.

MR. MOCK:—While we listen with interest to those who advocate the application of the Diesel or similar cycles to automotive purposes, I can see no particular advantage in blinding ourselves to the practical limitations that we all know exist. In the matter of fuel consumption the chief reason for the low efficiency of our passenger-car and truck engines is the fact that they operate so much of the time at part load, under conditions of low mechanical efficiency. If we examine the Diesel engine as to its part-load characteristics, I am very sure we will find that its slightly greater expansion-ratio efficiency will not compensate for the power lost in driving the various auxiliaries that it requires, and that actually its fuel consumption would be higher than that of present Otto-cycle engines. Further, everyone who has worked with carbureters knows that it is a practical impossibility to run a multi-cylinder engine smoothly at various loads and speeds with the fuel feeds individually regulated for each cylinder. Even if this could be done, I doubt very much whether a multi-cylinder engine could be made to fire at all smoothly at low loads by a reduction of the fuel feed. Consequently, the only high compression self-ignition engine that could be used would be the one-cylinder or limited load-range type of engine. Such engines would be tolerated only in motorboats or tractors, for which service they are not particularly adapted on account of the careful attention that is essential to their satisfactory operation.

MR. ZIESENHEIM:—A thing is never possible until it is done; that thought keeps the inventor struggling along. One question about the fuel characteristic shown in Fig. 2 of my paper is whether that will remain stationary? If the end-point of the fuel continues to rise and we must add heat to the fuel to vaporize it, we will have to continue to add more dope all the time, because the temperature at the end of compression will be higher. Referring to Fig. 4 of my paper, for a difference of 42 deg. initial air-temperature at 400 lb. per sq. in., say, we have over a 100-deg. change in temperature. This means that if we have an engine with a compression of 60 lb. per sq. in. and must heat the fuel 40 deg. above that normal compression temperature, we have as high an end-temperature as we would have with a compression of about 120 lb. per sq. in., which means that we must add a considerable amount of fuel dope.

MR. MIDGLEY:—It is not necessary to add much fuel dope.

MR. ZIESENHEIM:—The performance of the Diesel engine at part load is much superior to that of the Otto-cycle engine, particularly one of the throttling type. There can be no question of that; anyone who ever looked at comparative fuel curves can see it. I admit that the Diesel engine for automobile use is not an immediate possibility by any means, but its assumption of heavy-duty truck, tractor and marine work would certainly be of infinite benefit to the automobile industry and relieve the fuel situation considerably. From that standpoint alone it is worth developing.

ROBERTSON MATTHEWS:—The advocacy of the high-compression engine before the Society is in order, as is shown by the curves representing the fuel situation and the change in volatility of engine fuels in recent years. The elimination of the spark-ignition and carburetion elements of the Otto engine, as well as of the complex air-injection system of the Diesel engine, are much desired achievements, especially in connection with small high-speed engines. The large number of individuals and

laboratories who are striving to bring about this elimination is indicative of its great importance and leads to a desire for more published information of experiments and designs that have not been successful. There is much needless repetition of research and, as history shows, the difference between success and failure depends upon small variations of conditions. Careful and many-sided analyses of a supposed failure may point out the real path to success. Wise selection of narrations of such failures might tax our editors but, as has been said, there is a right sort of even nonsense.

With a scarcity of information respecting conditions that have not brought flexibility of operation with high thermal efficiency from small high-speed engines, there are many things that those of us attacking this solid-injection problem would like to hear about. Mr. Ziesenheim states that the average automotive engine operates at only one-third its rated load most of the time. Some test reports of large Diesel engines show remarkably flat fuel-economy curves with change of load. Can Mr. Ziesenheim give us any assurance that such flat fuel-economy curves can be obtained with small cylinders and with solid injection? We would like to know what the effect of slow speed, together with the large ratio of surface to volume of the small cylinder, may be upon the attainment of that temperature at the end of compression that is essential to cause compression ignition.

Has Mr. Ziesenheim found that at maximum load he can inject, under conditions favorable to freedom from detonation on the one hand and excessive maximum pressures or freedom from after-burning on the other, even light fuel oils in the short interval available with engines turning at from 2500 to 3000 r.p.m.? Has he considered the pressure in the injection system necessary for such intense operation?

I emphasize somewhat that a disadvantage of the medium-pressure engine in starting is the necessity for preheating an ignition surface. Has not the introduction of an electrically heated hot-spot, for starting only, overcome in large measure that disadvantage? Among the advantages of the high-compression engine is given "ease and simplicity of operation." Is that statement consistent with the disadvantage stated as "educational work necessary for the operation and servicing of a new type of engine"? Some of us fear that a gain in thermal efficiency will be at the expense of care in design and of both care and vigilance in operation.

Does Mr. Ziesenheim think that the improvement in the operation of the Pittsburgh Filter & Engineering Co.'s Brons-Hvid engine over the Sears-Roebuck Hvid engine may be because of the larger combustion-space, allowing more freedom of movement of the fuel spray without its coming into contact with cylinder walls and piston head? It would be valuable for some of us to know whether Mr. Ziesenheim has proved by his own research on small engines that 18 deg. before compression dead-center is a suitable angle for injection to begin, and to what range of revolutions per minute that value is applicable; whether 350-lb. per sq. in. pressure is sufficient for obtaining compression ignition in starting a cold cylinder of automotive size; and whether, with the pressures necessary for the injection of fuel in the short interval available with the rotative speeds of automotive engines, the elasticity of the fuel will be only 2 per cent.

The temperature curves of Fig. 4 in Mr. Ziesenheim's paper would be more valuable if the assumed initial pressure were stated and also the value of the exponent for the pressure-volume relation. Failure to state the conditions upon which data are based is a common weakness in much of our engineering literature, and most of us who write can be found guilty.

It would be of interest to hear from other investigators of the difficulties they have encountered with lapped and packed joints; also, about their experiences with valve systems that would not hold, and of their observations concerning the compressibility of the fuel itself. Perhaps someone may have learned how to abate the nuisance of air in the fuel feed-lines. What is the best filtering system that has been discovered for the fuel-feeding system?

Since most of the solid injection will eventually be for multi-cylinder engines, it may be worth while to compare a statement of Mr. Ziesenheim with a statement by G. Ure-Read in *The Engineer* (London) for Nov. 14, 1919. The former states

> With the injection-valve filled with fuel maintained at constant pressure and the fuel cam acting directly on the injection-valve, the injection action can be much more rapid than with the variable fuel-pressure generated by a cam and pump removed from the injection-valve.
>
> The constant fuel-pressure obviates trouble from the elasticity of the fuel and its containing system and also does not permit the entrapped air to expand and cause erratic injection.

The article in *The Engineer* states

> The cards were all taken from the same cylinder of a multi-cylinder engine. . . . .
>
> The engine was operated on the solid-injection principle, and so arranged that two methods of applying this system were possible; one where each cylinder has a separate pump discharging through an accumulator to its spray-valve, and another where the separate pumps discharge through their accumulators to a common pipe, and then to the spray-valves. . . . .
>
> In each group it will be noted that the revolutions per minute and the mean effective pressure are greater for the separate than for the combined system, notwithstanding the fact that the measured quantity of fuel per stroke was the same in both cases. The reason put forward for this result is that the capacity of the fuel system when each cylinder is fed separately is smaller in comparison with the capacity of the pump than when the combined system is used. Hence, the fuel pressure is greater when the spray-valve opens. . . . .
>
> In Figs. 2, 4 and 6 of this article, which show superimposed cards for the two methods, there is an appreciable difference in the point at which the pressure begins to rise, owing to combustion.

In presenting the possibilities and difficulties of applying high-compression and solid injection to the small high-speed engine, the Society is doing work of vital importance to the entire engineering profession and to the public.

P. L. SCOTT:—Mr. Ziesenheim's able presentation of the subject of automotive development of injection engines appeals to me as particularly apt at this time. There is much good opinion that the fuel situation will not compel us in this direction, but the problem has been before us for some years and has several good reasons for its appearance in addition to the aspect of great fuel conservation. If we are to accept injection as the most promising trend for automotive development, it is time that intensive study of the matter should be begun.

Heavy-oil engines for automotive purposes are often urged on the ground that they will burn the "heavy oils," which is only a half statement. Injection engines will burn whatever is most readily and cheaply available. This is something that no carbureting engine will do,

although it is possible to persuade many of them to include some range of fuels by adjustment and patience with increased trouble. Carburetion and electric ignition are more or less sensitive to variations in atmospheric and other conditions. Injection with compression ignition is not, and requires no field adjustment under any condition. Further, losses due to throttling are absent with the injection method of handling the fuel.

Mr. Ziesenheim points out that detonation can be overcome entirely by injection, with any fuel. It can be stated further that it is possible to control the combustion completely with injection. The process can be visualized as an intermittent torch introduced within the cylinder, the starting and stopping time of which is regulated and the flame of which is controlled to a nicety to obtain the best sort of chemical reaction. It seems to me that the matter of adaptability of injection systems to existing types of engine should be emphasized in such development. To make an injection system readily adaptable to present engines, the pressures must be kept low and a high degree of simplicity and reliability is essential.

Injection with spark ignition is mentioned. There also seems to be a possibility in the use of what Mr. Ziesenheim classifies as medium compressions, but with true Diesel operation. Such operation removes most of the objections given against medium-compression and puts it nearer the high-compression class. We have found it possible to secure reliable ignition, with one form of atomizing valve, at 250-lb. per sq. in. compression and have gone lower. The injection is timed 5 deg. ahead of dead-center with 300-lb. per sq. in. compression and continues through about 40 deg. for an engine running at 500 r.p.m. Ignition takes place within 3 deg. of the appearance of the spray, and engine cards together with spray diagrams show a fairly faithful following of the burn according to the rate of injection. Maximum brake mean effective pressures have been raised to over 90 lb. per sq. in. under favorable circumstances, although the exhaust is smoky. The engine is of the double-piston Junkers type, weighing 1370 lb. and developing 30 hp. normally at 500 r.p.m. The load has been increased to as high as 50 hp.

Mr. Ziesenheim concludes, broadly, that the variable-pressure system is suitable only for slow speed and rather "rough" constructions. The systems classed as variable pressure have so much to recommend them in mechanical simplicity and reliability that they deserve the fullest consideration and, in the light of experience, I would not concur entirely in this conclusion. It is true that elasticity or air-binding may upset the variable-pressure system. But the air-binding difficulty can be overcome by designing the pump to eliminate the air or liberated gas continuously, before it reaches the atomizing valve. Leakage is possibly not so important, because a few drops per minute is readily visible to the operator; whereas it takes several drops per injection to have a marked effect. Leakage can be held to a negligible quantity by reducing the number of joints and using satisfactory forms. Further, the trouble with pump-plunger leakage can be overcome by making the pump without a stuffing-box. After building several pumps without stuffing-boxes to handle from 0.1 to 0.2 cc. (0.0061 to 0.0122 cu. in.) maximum per stroke at pressures up to 10,000 lb. per sq. in., I am convinced that this is a good construction and certainly lasts much longer. The leakage past the plunger, in such pumps, can be reduced below a measurable quantity. With an indicating device for recording the start and stop and also the variations of the injection, it has been determined that it is possible to hold the timing within 1 deg. and the characteristics of injection within a few per cent, with an automatic valve, as regular performance.

The constant-pressure system has two disadvantages that are not mentioned; namely, that the valve-gear to obtain the very small lifts required, which are only a few thousandths of an inch, is a most refined piece of work, and wear or lost motion changes the timing as readily as air will throw the variable-pressure system off. Then the constant-pressure system increases the pump work by 100 to 200 per cent, which is an appreciable amount taken from the indicated horsepower. The mechanically operated valve also requires a high-pressure stuffing-box. Further, with mechanical-valve operation, it is impossible to obtain exceedingly minute valve-openings, with the consequent high degree of pulverization and very high velocities so important in securing good "penetration" of the spray. It is difficult to throw a finely pulverized quantity of oil across several inches of compressed air.

In the development on which some of the foregoing statements are based, the valve is automatic and injects at practically constant pressure, but the fuel supply is under variable pressure. The opening is produced automatically and is in the neighborhood of 0.0001 in. The resulting average velocities are about 10,000 ft. per sec. minimum and may reach 20,000 ft. per sec. An estimate of the velocity of a molecule of hydrogen under standard conditions is 5000 ft. per sec.; so, it will be noted that the momentum of the particles is in the neighborhood of the momentum of the molecules of a gas under high pressure. The mass of the molecule of any ordinary fuel is far greater than that of any of the constituents of air, and a particle of even very finely pulverized fuel contains a comparatively large number of molecules.

C. A. NORMAN:—Mr. Ziesenheim's paper is a remarkable contribution, on account of the thoroughness and impartiality with which injection-engine developments all over the world have been scrutinized and discussed. Such a scrutiny will help to avoid many errors, often costly. It will also furnish encouragement by showing that injection engines of the types simpler than the Diesel engine are now in operation in several parts of the world, and only await adaptation to automotive sizes and speeds. Such adaptation has in part already taken place in the case of the Junkers,[10] the Steinbecker,[11] the Brons-Hvid and the Blackstone engines, and in a perhaps somewhat more experimental way in the case of the Diesel engine itself. As most of these developments have occurred abroad, it is to be hoped that there will be no further delay in beginning similar developments in America. The work of E. A. Sperry[12] in this connection is most gratifying. Let us hope that Mr. Ziesenheim's experimental work will likewise meet with success.

R. M. HVID:—I have read with interest that part of the paper in which Mr. Ziesenheim makes a statement of the advantages and disadvantages of the Hvid engine as compared with other types. However, I am forced to the conclusion that he could have been in possession of only very superficial information regarding the Hvid engine and its developments here and abroad, and that he certainly has had no direct and general experience in its construction and design. Consequently, the conclusions he reaches with reference to it are inaccurate and misleading; they are not based on facts.

Mr. Ziesenheim states that the Brons-Hvid engine has been in existence nearly as long as the Diesel engine and

[10] See *Automotive Industries*, Oct. 7, 1920, p. 718.

[11] See *Automotive Industries*, March 3, 1921, p. 501; and *Power*, Oct. 12, 1920, p. 584.

[12] See THE JOURNAL, November, 1920, p. 454.

that it has achieved no success in Europe or America except as distributed by Sears Roebuck & Co. He states also that it is about 28 years since Doctor Diesel invented the Diesel engine. As a matter of fact it is 14 or 15 years since the first Brons engine was built. The first firm in Europe to build Brons engines had built from 200 to 250 engines up to 1911. Since then and in spite of the war several thousand engines of this type, from 4-hp. single-cylinder to 480-hp. six-cylinder, have been placed in service in Europe and other continents by the Brons Co., Holland; the Deutz Motorfabrik, Cologne; and Laurin & Clement, Bohemia. That these engines are giving universal satisfaction to users is indicated by the fact that, according to recent direct reports, orders are booked far in advance. I introduced the Hvid engine into this country and the first engines were built and placed in operation in 1913-1914. They can be obtained now from 21 different firms and the number constructed up to this time is several times 10,000. Other firms are under license and expect to have their engines ready for their trade soon.

Referring to Table 1 of Mr. Ziesenheim's paper, the conclusions reached from the data given in it are of very little value, as prices and ratings are only momentary, particularly in these times. That is well illustrated in this case by the fact that prices and ratings on the Hvid engines as stated in Table 1 were changed even before advance copies of the paper were received. The result of these changes is so great that instead of the Hvid engines costing an average of 84.1 per cent per b.hp. more than gasoline engines, as stated in Table 1, they cost only 20.5 per cent more; and, instead of costing $0.259 per lb., they cost only $0.177 per lb. In fact, the Hvid engines now cost a fraction less per pound than the gasoline engine.

The Sears Roebuck & Co. engine of the Hvid type, as well as the other builders' engines, are sold on a liberal guarantee covering economy, simplicity and reliability; and, while consideration has of course been given by the designer to the class of trade the engines are intended for, the fact remains that they will develop their full rated horsepower indefinitely, with the degree of regularity necessary for the service intended and with excellent fuel economy. Their success cannot, as Mr. Ziesenheim states, be attributed in part to almost exclusive use of kerosene as fuel, as this is not the case. Neither can their success be attributed in part to the elimination of crankcase dilution by the particular design adopted by Sears Roebuck & Co., because there is no crankcase dilution to eliminate in the Hvid engine as this term is generally understood, provided of course that the compression is maintained and the valves and the piston-rings are tight. This is perhaps best proved by the fact that several builders of vertical Hvid engines employ the common splash lubricating system for the cylinder and all the bearings in the crankcase, exclusively; one has done so for more than 10 years. The builders' general instruction to users is to renew the lubricating oil in the crankcase but once in three months, when the engine is used daily.

Excessive pressures in the cylinder of the Hvid engine do not occur except through misuse or when the valve-gear is out of adjustment. A compression-pressure of 425 to 480 lb. per sq. in. is recommended, depending on the size of engine and to some extent on the nature of the fuel oil. It has been found, however, that a wide range of fuel can be handled by the engine without any change in the compression-pressure. The maximum explosion-pressure in the cylinder is approximately 600 to 625 lb. per sq. in. It has not been found necessary, even in the large type of Hvid engine, to fit safety-valves to the cylinder-heads, such as are commonly fitted to Diesel engines. It has been found that if a Hvid engine is designed to withstand the same normal pressures as a similar size of Diesel engine, its strength is ample. This has been demonstrated in several thousand engines that have been in use for several years.

Regarding the fuel-cup, Mr. Ziesenheim seems to think this is a very difficult problem. As a matter of fact, it is very simple if we avail ourselves of the data that have been accumulated since these engines were first brought out. Even if such data were not available, a good engineer would easily find a suitable one after testing two or three fuel-cups, and certainly it would be a much easier task to design a proper fuel-cup for a Hvid engine than to design the injection-valve and its appurtenances for a Diesel engine. The fuel-cup is not such a delicate and sensitive part of the engine as Mr. Ziesenheim seems to think, and a fuel-cup decided on for a certain size of cylinder will handle a wide range of fuel, load and speed. Up to the present, cylinders of diameters ranging from 3 to 16 in. and with 33 intermediate sizes, with 42 different displacements, have been built and are in operation. Full data are at hand for the fuel-valves on all these engines, and engineers to whom such data are available should have little difficulty in designing the proper fuel-cup for almost any size of engine and for all ordinary conditions.

Whether the Hvid engine has the ideal conditions for pulverization of the fuel oil, I do not know, but I do know that the engines of the Hvid type will show excellent economy and maintain it with very little attention. On the larger sizes of engine, say from 60 to 80 hp., one firm guarantees a fuel consumption of 0.41 lb. of fuel oil per b.hp-hr. and even on very small engines a fuel consumption as low as 0.5 lb. per b.hp-hr. is easily obtainable. So far as I know, this is as good or better than has been obtained on the best engines of other types in similar sizes.

I fail to understand Mr. Ziesenheim's objection to the needle-valve governing. It is undoubtedly the simplest device that could be used, it has been found perfectly reliable at all times and any degree of regulation on the engine can be obtained with it. Mr. Ziesenheim states that the cutting-off of the fuel supply is not effective until after the result of several strokes have been discharged and burned and that consequently there is trouble. This is impossible unless the governor connections are defective, as the volume of the fuel oil in the small passage between the needle-point and fuel-valve is so small that it only contains a very small fraction of the amount of oil necessary for a full power stroke. This form of regulating the Hvid engine has been used for many years on single and multiple-cylinder engines, and there is no question about its reliability or that it is adequate for any service the engines might be put to, even if it does seem too elementary to some.

As to the possibility of a small quantity of fuel being drawn into the combustion chamber of the engine during the suction stroke, of which Mr. Ziesenheim speaks, it is possible that a very small quantity is drawn in, but if Mr. Ziesenheim had had more experience with this type of engine, he would have found that this enriching the air in the cylinder very slightly is of great benefit. The trouble that Mr. Ziesenheim thinks may come from this fact does not occur and, with reference to sticky pistons and piston rings, this trouble does not occur either if the piston is properly fitted in the first place and correctly

lubricated. Engines are known to have been in operation several years without requiring the pulling of the piston for cleaning or on account of loss in compression. Exhaust-valve troubles also are rare, as the combustion is clean and almost colorless.

Looking over the records for the engine built by the Pittsburgh Filter & Engineering Co., Oil City, Pa., I find that it was started for the first time on March 25, 1919, and that the testing period was finished Jan. 19, 1920, or 9½ months; at that time the engine was put in daily operation carrying the shop load. It has been doing its work since then to the satisfaction of the builder. From this record I find also that, during the testing period, less than two months was actually spent in testing and selecting the proper fuel-cups to meet the builder's requirements for this four-cylinder engine. This period is not excessive, in my opinion, considering the length of time it took to try out and decide on the other more or less standard features of the engine.

W. P. DEPPÉ:—I am somewhat astounded to note that not a single reference is made in these very able papers to the possibilities of homogeneous mixture-charges having the properties of gases in their superheated state before ignition. Combustibles in air must be transformed into gases in the superheated state before ignition and raised to the temperature of so-called ignition or combining points with oxygen before one can start the cycle of physical, chemical and electrochemical actions and reactions involved in this problem. Merely taking readings on tests of combustibles in air, and then taking similar readings on the products of combustion, certainly do not give any idea or measure of the transformations that are involved in the production, maintenance and delivery to the cylinders of a fuel charge in the modern internal-combustion engine. Further, all the authors seem to overlook the cycles involved in the fuel mixture when suddenly taking them out of partial vacuum and putting them under compression, as is done in the intake-pipes and cylinders of the modern vehicle engines. In addition, none of the authors seem to have considered at all the advantages of preventing altogether the so-called preignition under high compressions or preventing peak-pressures after ignition, due to the so-called autoignition or flame speeds producing so-called detonation, because of the heterogeneous mixtures before and after ignition, and heterogeneous flame speeds in different parts of the mixture charge after ignition.

There is no more wonderful mechanism in the hands of the public today than the four-stroke-cycle throttle-controlled internal-combustion engine operating on liquid fuel. It seems astounding to one contemplating seriously for one moment the fact that in wet-mixtures of fuel one is trying to perform all the functions of an oil refinery, city gas-works and the like, between the moment of ignition and that of actual power-pressure in the cylinder. By the correct use of superheat and the proper ratio of combustible, air and the products of combustion, under suitable operating conditions and limits, one can readily produce, maintain and deliver the fuel mixtures in such a way as to give all the properties of a homogeneous mixture of gases in the superheated state with preignition entirely eliminated and also auto-ignition and peak-pressure after ignition; further, with properly controlled combustion, one can give the qualities of throttle ability similar to those of the steam engine.

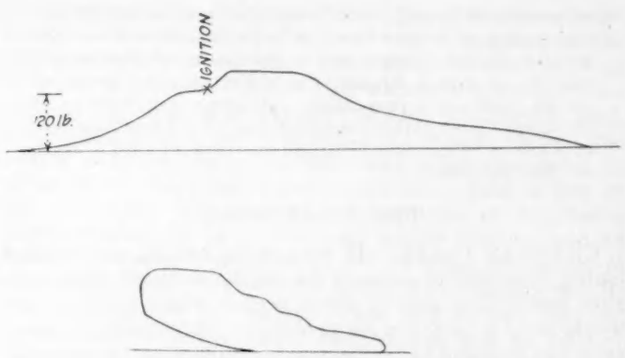

FIG. 15—TWO INDICATOR CARDS TAKEN FROM AN INTERNAL-COMBUSTION ENGINE
The Upper One Was Taken from a Six-Cylinder Engine Operated on a Controlled Combustion Superheated Basis While the Lower Shows the Controlled-Compression and Combustion Pressures without Doping the Fuel or Altering the Wet-Mixture Design

The upper portion of Fig. 15 is a Midgley curve showing the Spillman six-cylinder-engine indicator-card at 2200 r.p.m., which has all the characteristics of a steam-engine card, when operated on a controlled-combustion superheated basis. The lower portion of Fig. 14 exhibits also a Midgley card showing the controlled compression-pressures and controlled combustion-pressure without "doping" engine fuels, without altering wet-mixture design of engines, and doing nothing further than prepare the fuel properly and coordinate all the natural elements involved in this subject, and operating simultaneously and progressively in the complete cycle of events involved in this problem.

These conditions in superheat methods give very high mean effective pressure with somewhat lower maximum combustion-pressures than wet mixtures, and will enable the oil refiners to crack 80 to 90 per cent of all the crude oils in the world for suitable engine fuels with present commercially developed cracking methods of the continuous cycle of processes whenever the automotive industry simply decides to face the unfortunate conditions mentioned in the papers referred to and to improve them.

PRACTICE AND THEORY IN CLUTCH DESIGN

BY HERBERT CHASE

THE objects of this paper are to (*a*) set down in convenient form for reference purposes particulars concerning American and British practice in clutch design, (*b*) compare the advantages and disadvantages of various types of clutch and (*c*) give some notes on the theory of design without attempting comprehensive treatment of the numerous factors involved.

The descriptive portion deals almost entirely with clutches used on passenger cars and trucks, but some of the clutches described are applicable to other automotive uses. The notes on the theory of design apply in general to all automotive clutches.

The clutches considered are divided into the four general classes of cone, single-plate, multiple-disc and

shoe-or-band types, these being discussed at length and illustrated with drawings. After a consideration of the details of their design and a brief presentation of the subject of clutch brakes, the notes on the theory of clutch design are presented. An important feature of this paper is an elaborate tabulation of the specifications of various clutches.—[Printed in the July, 1921, issue of THE JOURNAL]

THE DISCUSSION

CHAIRMAN CRANE:—If we simply had to deal with a clutch intended to connect an engine with its transmission mechanism and to disconnect it when required, we would have a very simple problem. Unfortunately, however, the problem of temporary disconnection for the purpose of shifting gears brings in a question of spinning weights that militates against the best design of clutch for simple purposes of transmission. If that is given consideration, one will see just where the limitations of a cone clutch have been. Unfortunately, the larger the engine is or the greater the torque the engine is capable of delivering, the more difficult the problem becomes from the viewpoint of gearshifting, because the parts become heavier and heavier while the speed variations required to be accomplished in gearshifting remain the same. A cone clutch of small diameter can take care of such conditions and still provide sufficient surface with an engine of small torque capacity. With an engine of large torque capacity, it cannot do so.

One very well known foreign car uses a cone clutch, and I am informed that it is impossible to shift from high gear to the next lower gear at any high speed without resorting to what is called double-clutching; withdrawing the clutch, shifting the gear into neutral, allowing the clutch to reengage and speeding up the engine to speed up the clutch mechanism and the lay shaft in the gear box, and throwing in the gear after again disengaging the clutch. An expert operator can do this and make a very good showing with that type of clutch, but the average driver cannot do it at all. He is forced to a very noisy gearshift, which also results in excessive strains on the gear teeth, or else he cannot expect to shift down on his gears except at very moderate speeds, which seriously interferes with the efficient driving of a car.

I have noticed a tendency to misunderstand the function of the clutch brake in gearshifting. The clutch brake is of use in shifting from a lower to a higher speed because at that time a slowing down of the spinning parts is required; but it works entirely against the operation in shifting from a higher to a lower speed, and this is the shift that is most difficult to make and occurs usually at a critical time on a hill when it is most desirable to maintain the motion of the car. The only cure to accomplish good gearshifting under those conditions is the light spinning weight. It is a very difficult problem on a big engine to strike the correct compromise.

A clutch of very small diameter appealed to me very strongly about a year ago until after I made a thorough study of it. I found that, due to the small diameter and therefore to the small radius with which to absorb the torque, it presented an almost impossible problem, and that one is practically forced into using a friction surface of fairly large diameter to do the work.

As a matter of interest, there is a clutch installed on one car, experimentally, that uses a disc 1/16 in. thick as a spinning member. I think it is not a commercial proposition, but in careful hands it operates extremely well. With the lubrication that I think it deserves, the single-plate clutch has resulted in absolute immunity from wear on the friction surfaces outside of the plate, in my experience. An experience of 10 years and upward of 100,000 miles of service have not resulted in the replacement of a single fabric facing in clutches of that type, the reason being that the lubrication of the fabric is sufficient to replace the natural loss of binder due to the heat conditions of operation and maintain the fabric in practically its original condition. A dry asbestos fabric without any binder is about the flimsiest piece of woven material that has ever been seen. There is no real continuity to the fibers and the thing cannot stand. With a proper binder it is an extremely durable material.

W. E. LAY:—Another contradictory thing about a clutch is that when on high gear or in hard pulling one wants it to stick but, when trying to start the car, since the car is still at rest and the engine will not pull at practically zero speed, the engine must be running when the car is standing still and there must be slipping. That is true also when changing gears.

CHAIRMAN CRANE:—That part is obtained very simply by the variation in spring-pressure obtained through the foot-pedal. The worst difficulty is that it is necessary to have the slipping friction sufficient to stall the engine and not the standing friction alone. That difficulty has been experienced in certain forms of the multiple-disc clutch; the friction of the discs on the splines has been sufficiently great that, if the engine is speeded up and the clutch allowed to begin engagement, the full spring-pressure is not obtained on all the discs. It has been obtained on the first disc but, due to friction on the splines, each succeeding disc has a little less pressure on it. Before the clutch is actually engaged by reducing the throttle-opening so as to relieve the torque momentarily, the clutch does not take hold.

B. B. BACHMAN:—Will Mr. Chase elaborate further his reference to gear teeth? As I understand it, gear teeth are purely the internal and external form of tooth in which line contact is, of course, obtained. But there are methods of generating what are approximately tooth forms that have full line or full surface contact, and to all intents and purposes are what he mentions as keys. Another item that is an important factor in clutch design is the matter of the bearing surface between the plates and the driving means, the range of bearing pressures. I am sorry that Mr. Chase did not have such data to present. If we had the figures on that subject, I think that the variation in the pressure allowed on the splines of driving plates would be found to vary so widely as to be startling.

Another point is the question of the ball bearing. It has been my experience that the use of a ball pilot-bearing is in some instances beset with difficulties, because it is almost utterly impossible to get lubricant to it; furthermore, in a number of forms of clutch, what lubricant does reach it contains a certain amount of road dust or rubbings from the clutch surfaces that the lubricant picks up and holds and possibly more trouble is caused than if there were no lubrication. I do not mean to say that the plain bearing is entirely free from difficulties of that sort, but I do believe that there is a field for investigation and further development of a bearing that is so thoroughly hidden that it is not accessible and cannot be seen without much dismantling.

MR. MOSKOVICS:—An interesting type of clutch that Mr. Chase has not described was known as the Langdon and was used in the Mercedes models. It has the one feature of being practically a locked type of clutch when it was finally engaged. It has good slippage and is very light. I think some cars are still using that type of clutch

in Europe. There are difficulties with regard to its practical production, but that should not prevent us from finding out about it; eventually, we may learn how to make it at lower cost.

CHAIRMAN CRANE:—We overhauled a 1906 Mercedes which had that type of clutch. We called it a wind-up clutch. It consisted of a very small-diameter hardened drum and a hardened square-section coiled spring. The operation of the clutch was not particularly simple, especially in city usage. It was apt to grab and we were warned to be extremely careful about slipping it for any length of time, due to the rapid wear. The gearshifting on that car was certainly a joy. One could snap the lever with one finger at 30 m.p.h. and go from third to fourth speed without a sound from the gearbox. But I doubt if the clutch would have been satisfactory as a commercial proposition. The surfaces were so small and the pressures so high that it could not withstand the kind of slipping that exists in the rough everyday service of the average owner and driver in this country.

JOHN MCGEORGE:—That same clutch was used on locomotive cranes built by the Browning Co. in Cleveland; it withstood some of the hardest and roughest usage to which it could be put. I know of no rougher clutch usage than is found in locomotive cranes. In a much larger and heavier form it also has had rough heavy usage in the rolling mills of England.

HERBERT CHASE:—In the clutch of small diameter, it is true, as Mr. Crane has said, that the torque is high at small radius, but it is practicable, especially in the multiple-disc type, to maintain a small diameter and get the advantages of low spinning weight and decreased inertia of the driven member while still securing ample capacity with moderate spring-pressures.

Mr. Bachman mentioned the matter of gear-teeth contour and the area of tooth bearing surface. With a proper tooth-contour the contact area is the same as with keys or splines.

The matter of pressures on splines is a very important one and I regret that data were not collected in this regard. It is a distinct advantage to avoid the use of splines at a small diameter. This can be done in certain types of clutch, particularly in the gear-tooth and key type of multiple-disc clutches described.

The pilot bearing deserves much study. There is a wide diversity of practice in applications; some prefer the ball bearing, some a plain bearing, and some a so-called oilless type. They are all mentioned in my paper. In some designs the British arrange to lubricate the pilot bearing by pressure, with oil in the hollow type of crankshaft, putting a plug of wicking or similar material in the hole connecting the two to prevent too rapid a flow. The difficulty, however, is that over-lubrication may result and oil reach the friction face, causing slippage; or that the oil duct will become filled with sediment and the oil supply fail.

The only reason I did not mention the Mercedes clutch along with a number of other types that have been used by a few makers is the fact that it is not used extensively to-day. It has some advantages, but it has the disadvantage that Mr. Crane mentioned of grabbing unless very carefully handled. The several disadvantages of the disc type in oil are set forth. The primary disadvantage is the lower coefficient of friction.

D. E. GAMBLE:—Mr. Chase is to be congratulated on this interesting and timely treatise on clutch design, for it is generally admitted that this unit has not received the attention that the other essential units of motor cars have enjoyed. On behalf of the single-plate clutch I will call attention to a few points that may have been overlooked. First, as to the objection to a decrease in the spring-pressure when wear takes place at facings, it is possible to compensate for this decrease by proper design of the lever or toggle devices. In the Borg & Beck clutch the actual plate-pressure is greater when the sleeve is in the inner position than when the clutch is adjusted to the proper sleeve position. This is due to the fact that the mechanical advantage of toggles is approximately 10 at the original set-up position and 13 when the sleeve is worn in ¼ in. A great advantage of the single-plate clutch is its ability to dissipate rapidly the heat caused by friction. The use of the flywheel proper and a rather heavy cast thrust-ring as friction surfaces is ideal for conductivity and dissipation and, in addition, it is common practice to use a moderate section of cast iron in the driven plate. This plate is cast integrally with its hub and therefore there is much more surface and mass available for dissipation than is possible in the very thin stamped steel plates necessary in multiple-disc construction. After a short period of slipping at high torque the plates of a multiple-disc clutch are generally burned and warped beyond repair; whereas the cast-iron disc in a single-plate clutch under the same conditions will withstand considerably more abuse. Of course, such abuse is not recommended in any clutch, for ample gear-reduction is available in all modern vehicles for the proper increase of torque at the wheels.

This matter of heat dissipation is of extreme importance, for it affects vitally the wear of facings or, more properly speaking, the reduction in thickness of facing. We have found in conducting facing tests that under ideal conditions such as ample torque capacity, moderate unit-pressure and minimum slip during engagement, there is practically no wear on the facings of either the woven or molded type of asbestos material. However, when a clutch of any type is slipped at high torque over extended periods, the facings are rapidly reduced in thickness, due, we firmly believe, to destruction by heat rather than abrasion. This theory is supported somewhat by service reports from many manufacturers to the effect that some customers have obtained service in excess of 20,000 miles without clutch adjustment, whereas other customers require clutch adjustment every few hundred miles. It is hardly probable that the heat generated during the periods of slip approaches the temperature of 1500 deg. fahr. necessary to dehydrate the asbestos, but it is likely that a surface temperature of 800 to 1000 deg. fahr. is often obtained and this tends to destroy the binder used in the manufacture of all of these asbestos products.

It is extremely unfortunate that many applications of single-plate clutches have not received proper attention in the matter of unit-pressure. There is of course a great temptation to select the smallest and cheapest clutch that will transmit the required torque satisfactorily, and the single-plate clutch, on account of the very high pressure made possible by the multiplying levers or toggles, is capable of transmitting an enormous torque with a comparatively small diameter. Due consideration must always be given the service required of the vehicle, its weight, gear-reduction and the frequency of clutch engagements.

Smoothness of action is in my opinion very largely a matter of accurate production and proper care in assembling to insure proper alignment of surfaces. It is obvious that the buyer is now much more critical as to performance than formerly, and I believe all clutch manufacturers realize that the quality of workmanship on

clutch parts must be brought somewhere near that maintained in the case of transmissions and axles.

ARTHUR B. BROWNE:—A study of the various designs of the four types of clutch shown by Mr. Chase will convince anyone that the same engineering ability that has been exercised in other units of the motor car has not been applied to this important unit. The Society should be congratulated on placing upon its records the valuable collection of data contained in this paper, which preserves in convenient form for ready reference the essential details to enable the car designer to select the unit best suited to his individual requirements.

Heretofore, first cost has been of greater consideration in the selection of clutches than has been the case with many other units, and yet there is no unit of motor-car construction with which the driver-owner comes into more intimate personal contact, nor which can make or mar the reputation of the manufacturer more quickly or more effectively than the clutch. The modern motor car owes its popularity to its ease and smoothness of operation; consequently it is the more disconcerting to have one's back suddenly thrown against the cushions by a harsh engagement of the clutch, or, on the other hand, to have a racing engine give warning on the first piece of sandy road that a visit to the next garage is necessary for clutch adjustment. The sale of many a car has gone to a competitor because of the difficulty of gear-shifting and many a stiff clutch-spring has resulted in just complaint on the part of the truck driver, with its certain reaction on the owner and manufacturer. The reasons for all these defects, and their remedies, are clearly indicated in Mr. Chase's paper and it is hoped and believed that more serious practical consideration will be given to the little understood and much abused clutch, as a result of its publication.

The fact that the multiple-disc clutch is used almost exclusively on the better grade of cars and trucks, at least in this country, is a practical argument in favor of the performance of this type that it is difficult to refute. The popularity of other types seems to have, as a sole basis, their cheapness of production and their availability as a market product. It would seem possible, in view of the data contained in Mr. Chase's paper, to design the multiple-disc construction so that, by production methods, its cost would at least minimize the advantage in this respect now enjoyed by the other types. In such design it would be advantageous to keep the mean radius as short as possible. Not only does this save weight of materials entering into the construction, with a consequent saving of cost, but, what is even more important, the radius of gyration is shorter and the inertia effects on disengagement are minimized, while, as Mr. Chase has mentioned, the wear on the smaller facings is actually less, due to the decreased linear speed during engagement. While it is true that the smaller facings are carrying a heavier load at the shorter radius, it must be remembered that this load is or should be carried without slip and that practically no wear occurs while the clutch is engaged but only at moments of partial engagement. The action of the shorter radius in reducing inertia effects is striking. With a reasonably short radius of gyration the use of a clutch brake is wholly unnecessary and without any brake whatever there is a freedom of gearshifting which must be experienced to be appreciated.

The formula given in the paper indicates that this desirable short radius can be secured only by multiple-disc construction, if due strength is to be maintained in the driven member of the clutch. With a given radius it is necessary only to have a sufficient number of discs to carry the maximum torque of the engine safely. With this number of discs it will be recognized speedily that a softness of engagement has been secured that is not commonly shared by other types of clutch. Adding a greater number of plates seems, in my experience, not to affect the softness of engagement materially, but the resulting increase of frictional area does add to the life of the facings or decrease normal wear. The proper number of plates therefore is the number necessary to carry the load safely, plus such other discs as the manufacturer is willing to pay for to give his product a longer life without replacement of the facings. It should be stated in this connection that, with modern clutch-facings of proper frictional capacity in sufficient number to carry the load with the proper spring-pressure correctly applied, the normal life of the clutch facings is more than sufficient to carry the vehicle past the period of otherwise necessary overhaul. None of the foregoing factors can, however, be minimized in its relation to the others, nor can the balance between them be disturbed without seriously diminishing the life of the facings themselves.

Mr. Bachman has raised one question that may well exercise the ingenuity of the members. This is the lubrication of the clutch pilot-bearing. In a somewhat wide experience I have never seen any adequate provision made for the lubrication of this bearing. Mr. Chase's statement that it does not need much lubrication does not detract from the problem; in reality it adds to it, because, while it is true that it does not need *much* lubrication, it does need *some* constantly, and it seldom gets any except that which the thoughtful assembler provides. A hollow clutch-shaft, or stem gear, is worse than useless for the lubrication of this bearing. It clogs after the first few miles. Pressure feed from the engine is apt to provide too much lubrication with resulting spattering over the clutch facings. I lean to the oilless type of bearing, but would welcome a more effective device for this, the most neglected bearing in all the chassis.

L. H. POMEROY:—Mr. Chase is in error when he states that clutches of the type shown in Fig. 18 of his paper, as used on the Vauxhall car, need to be run in oil. The Vauxhall clutch has been in successful use since 1910, the only lubricant used being powdered graphite. For this reason the somewhat formidable list of disadvantages of this type of clutch presented by Mr. Chase do not exist.

An additional advantage of the metal-to-metal disc clutch is that no provision need be made for adjustments of the clutch spring-pressure and, as the total wear after prolonged use is negligible, there is also no necessity for providing any adjustment for the position of the clutch-pedal itself.

MR. CHASE:—The reference to the Vauxhall clutch as being one which runs in oil is evidently in error. It is true, however, that metal-to-metal clutches require lubrication, graphite being used in place of oil in this case, with consequent reduction in the coefficient of friction. For this reason a greater number of plates is required as compared with the fabric-faced discs to carry a given torque with a given spring-pressure and size of disc. The cost and the spinning weight are therefore higher; hence, the metal-to-metal type is not without disadvantages. In some other makes of metal-to-metal clutch oil is used for lubrication, and in practically every case they are subject to the other disadvantages cited in my paper as resulting from this practice.

LUBRICATION

BY C. W. STRATFORD

LUBRICATION problems and the manufacture of lubricating oils are discussed in the paper. An outline is presented of the principles of lubrication; the sources, properties and manufacture of available internal-combustion-engine lubricating-oils; and similar factors regarding greases. Consideration is then given to these subjects.

Friction and its elimination are commented upon in a general manner, inclusive of comment on the best working temperatures for lubricants, blending oils and removing moisture. The various systems of lubrication are discussed; a classification of crude petroleum is made and the refining processes of the various grades of lubricating oils are outlined. Other subjects considered include the proper choice of lubricants, serviceability, available American engine lubricants, filtering and crankcase dilution. The composition and characteristics of the greases are reviewed briefly.—[To be printed in an early issue of THE JOURNAL]

THE DISCUSSION

CHAIRMAN CRANE:—I think the difference between splash and forced-feed lubrication is not so much in lubricating effect as in cooling effect. It is evident that a crankshaft running at say 2000 r.p.m. develops such great centrifugal forces that oil squirted or thrown at the crankshaft probably will not touch it at all, and that we will get but a very small amount of cooling by splash lubrication of the shaft and its bearings, especially those of the connecting-rod. In the type in which the oil is forced in large quantities into the crankshaft and emerges through the various bearings we have a regular source of supply to maintain the oil-film that is of course necessary, but, equally important, we have a very large source of supply to carry off heat.

We have found that the slow-running engine with fairly heavy duty can run satisfactorily on splash lubrication if the bearings are sufficiently large. The high-speed heavy-duty engine, however, has absolutely required lubrication by pressure to assure successful operation. This is especially true in airplane engines.

The thing of first importance in the installation is to give the oil a chance to settle as it comes from the bearings. Fortunately, there is a very large surface in the bottom half of the crankcase over which the oil is flowing at a rather slow speed and, as it flows down these walls, there is a natural tendency for the heavier solid particles to sink to the bottom. A very shallow trap at the bottom will catch these particles, if the suction inlet for the oil-pump is not carried to the bottom; bringing this point $\frac{3}{8}$ or $\frac{1}{2}$ in. above the bottom of the lower half of the crankcase is sufficient to provide for the settling feature. The use of large screens for the oil coming from the bearings is almost out of the question, due to the rapid clogging of a screen of sufficient fineness. On the other hand, a rather small screen of even 70 mesh, which we have used for a long time, placing it between the oil-pump and the bearings, will catch many small particles that have not been caught in the settling. A certain portion of the impurities is light in weight, such as sand and particles from the aluminum castings, and some lint or the like always comes through an engine that has been overhauled. Such materials will be caught in a fine-mesh filter without interfering with the flow of the oil produced by the power of the oil-pump.

J. N. HEALD:—Very few people appreciate adequately the tremendous waste of lubricating oil in an automotive engine. The amount of oil used is tremendous, in comparison with stationary steam-engine practice. In fact, a high authority on this subject has stated that automotive engineers should be concerned more with regard to the future supply of lubricating oil than of gasoline, and that the best engineering practice should be to give more attention to the conservation of the lubricating oil.

One source of loss of oil in an engine is the pumping of the oil up into the combustion-chamber, where it is burned without any useful effect. In fact, it simply fills the combustion-chamber with carbon and soot, fouls the spark-plugs and requires frequent scraping out and cleaning. Another source of loss is the dilution of the oil in the crankcase by gasoline passing down by the piston-rings, thus rendering the oil valueless for lubricating purposes.

These two sources of loss are due largely to poor machining and fitting of cylinders and rings. While the cylinder bores in the better grades of car are finished by grinding, thousands of engines for the less expensive cars are finished by simply boring and reaming. It is these latter cylinders that give the most trouble with respect to the loss of oil. The grinding process produces a hole that is almost absolutely round and straight; it has a highly finished surface, piston rings can be fitted so perfectly to such cylinders that pumping up oil is eliminated almost entirely and the leakage of gasoline past the piston-rings and into the crankcase is avoided. Rings also can be fitted with less initial tension, which cuts down the resistance to their motion, and therefore reduces the internal friction of the engine. It should be obvious that the grinding process, which eliminates two very troublesome sources of loss in the problem of lubrication, should be given more careful attention by many manufacturers.

W. G. WALL:—Is it possible, in refining lubricating oil, to eliminate all the free carbon? Is it desirable to do so? We know that when a crankshaft equipped for forced-feed lubrication revolves rapidly there will be a deposit. What proportion of that deposit is free carbon and also carbon washed from the cylinder walls, and what proportion is carbon due to the breaking down of the oil? Is the breaking down of the oil due entirely to the heat or partly to the centrifugal force of the crankshaft?

R. P. LAY:—Several solid and liquid preparations are being sold which manufacturers claim will remove carbon from the engine cylinders and pistons. Do such preparations have any effect on the carbon? Is there any way to remove carbon except to dismantle the engine and scrape it out?

MR. ZIESENHEIM:—The function of a lubricant is to prevent metal-to-metal contact of sliding surfaces by the shearing of an oil-film separating them. What gives to a lubricant the property of oiliness or unctuousness, is not entirely understood. Some writers maintain that the colloidal matter of the lubricant unites firmly, by a quasi-chemical action, with the bearing surfaces, and that it is the shear or sliding action of this colloidal matter that gives lubrication. What is Mr. Stratford's opinion of this theory?

C. W. STRATFORD:—As to whether it is possible to remove free carbon, there is practically no free carbon in finished engine oils. If an oil is distilled as in the

graphitic carbon residue test, at the end of the test there will be a certain amount of free carbon, but that carbon is due to its decomposition. There is no free carbon that one can filter out; the compounds that are filtered out are color-bearing compounds removable by Fuller's earth or Death Valley clay; they appear to be carbonaceous matter or peculiar chemical compounds.

In regard to the percentage of carbon in the carbonaceous sediment occurring in the crankcases of engines, I have never found it in excess of 2 per cent in hundreds of analyses. The 2-per cent case was due to very thin piston-heads; the oil was carbonized by being thrown up underneath and formed a cake, and that cake dropped down. Usually the so-called carbon deposit in the crankcase would be less than 1 per cent.

Concerning the carbon and the carbon deposit above the pistons, there also the percentage is very low, except where carbonization occurs due to using too rich a mixture, the carbon coming from the fuel and not the oil.

MR. WALL:—Is the deposit on the crankshaft, not the crankcase, due in any way to the centrifugal force of the crankshaft?

MR. STRATFORD:—In forced-feed systems like that used on the Liberty and some other engines, where there is a deposit on the crankshaft it is certainly due to centrifugal force, the crankshaft acting simply as a centrifuge, precipitating a sediment. I have never made an analysis of this deposit, but I believe that it consists of all the contaminating elements contained in crankcase oil at present.

OIL SPECIFICATION

W. M. BRITTON:—I have always believed that it might be possible to specify exactly what is required in lubricating oil. Oil representatives always state that it is aboslutely impossible to specify a lubricating oil in exact terms, and that one must simply follow their recommendations regarding oils and depend on their reputation. It has seemed to me that there are several vital qualities connected with a lubricating oil that could be expressed definitely. For instance, the viscosity of the oil at the particular temperature at which it will be used is vital. That can certainly be expressed. Probably the lowest temperature at which the oil will be used is fairly well known, and the cold test of the oil at that lowest temperature is certainly of importance. That can undoubtedly be expressed, for it is a well known property. The flash-point and the fire-point may or may not be of value in such a specification.

Another vital quality is the wearing property of the oil. The breaking down of the oil may be due to its actual mechanical use, or to the disintegration of the oil by the high temperature. Can the specific duty that the oil must perform be expressed for any particular purpose? It appears to me that tests could be made of the oil in a particular engine, and the effect of such use determined. The results of such tests could then be embodied in specifications for the oil that should be purchased.

There is also the question of paraffin-base and asphaltic-base oils. The producer of the asphaltic-base oil will say that if a satisfactory performance of oil is wanted in the engine, one must use asphaltic-base oil because the carbon that accumulates in the combustion-chamber is of a soft nature and does not solidify with the dirt that accumulates there and cause preignition. The refiner of the paraffin-base oil will say that one must use paraffin-base oil because the asphaltic-base oil will not stand up in the engine, disintegrates rapidly and is not a satisfactory oil.

MR. STRATFORD:—A flash test is usually made in the Cleveland open cup on lubricating oils and is an indication of the volatile products contained in the oil. By definition the flash point is the temperature at which the vapors arising from the oil will just ignite without igniting the oil. By making an extended study of the volatility of engine oils and distilling them dry under high vacuum, I found to my surprise that the flash-point of oils does not necessarily indicate the percentage of volatile products contained therein, as one would expect. It is my opinion that this is one line of research that merits considerable additional work. I am now setting up an outfit to continue the work that I have done, distilling under a high vacuum, also dry and with superheated steam.

HEAT TEST OF OIL

As to the possibility of writing into the specifications some test by which one can guarantee serviceability of the oil, I know of only one test that I think would serve in this way, and that is a very simple test called a heat test. The chemist of an oil company told me that some oils became black when heated. I used two flasks and what is known as an acidulated oil; also, as a second sample, I used a highly filtered spindle oil. I put them in the two flasks, put one on an electric hot-plate, raised the temperature about 500 deg. Fahr. and held it there for 10 to 15 min. I found that the acidulated oil broke up or turned black because of sulphuric acid that was freed on account of the heat decomposition immediately attacked the hot oil and precipitated a black sludge. I continued experimenting with this simple test and found that when finished engine oils are put in a small nickel-plated cup about 1½ in. in diameter and 1½ in. high, filled to about ¼ in. of the top, put on a hot-plate with a thermometer and the temperature of the oil raised to 550 deg. fahr., held there for 10 min. and then allowed to cool, there is an incrustation on the inside of the cup immediately above the surface of the oil. It is rather soft, as Mr. Britton mentioned, and it is carbonaceous regardless of whether the test is made on paraffin-base or asphaltic-base oils. The character of the carbonaceous deposits is very similar. There is also a formation of a gum or resin on the outside of the cup. At the high temperature the oil creeps up to the top of the cup and flows over. It undergoes oxidation and forms a gum or resin that is entirely insoluble in any petroleum product and soluble only in hot caustic alkali.

From long use of that method I think I am able to determine in the shortest possible time whether an oil is a good engine oil, but I do not know how to describe just how to do so. A poor engine oil will turn black when subjected to the test and, when held against the rays of the sunlight, appears to be of a very high robin's-egg-blue color. If it is a good oil, it will have an amber tone. When poured out of the cup, a poor oil will always leave a sediment; but a good oil will not. The appearance of the film on the empty warm cup is another means of judgment. The amount of evaporation that occurs during the heating of 10 min. duration is a good, although not exact, indication of the volatility of the oil. Anyone can make this test and in a very short time, I think, become an excellent judge of the quality of engine oils by using it only. It is very easy to determine the viscosity and, since it is one of the most important factors of lubrication, we have a standardized method of test for it. Before it will be possible to write into specifications facts that absolutely determine the properties fixing the quality of oils, we shall have to standardize methods. Much re-

search work must be done before a standardization of methods for testing the oils will be possible.

A carbonization oven gives an excellent indication of what will happen after an oil is in use in an engine. The equipment is rather delicate. By using an oxidation oven I was able to distinguish the difference between good and bad oils in 4 or 5 hr. I could check the results within less than 2 per cent.

THE MUTUAL ADAPTATION OF THE MOTOR TRUCK AND THE HIGHWAY

BY A. T. GOLDBECK

THE aim of this paper is to stimulate thought on how to accomplish the greatest possible economy in transportation over highways. The fundamental thought is that the expense of highway transportation involves a large number of items that can be grouped into those directly concerned with motor-truck operation and those involving the highway, and that highways and motor vehicles should be adapted mutually so that the greatest economy of transportation will result.

Urging that the automotive and the road engineer cooperate in gathering information that will give them a more definite basis upon which to design the truck and the road, the present rapid destruction of roads is discussed and remedial measures suggested. The designing of motor trucks to conserve the roads is treated at some length and a plea for cooperation between the society and the highway officials is made. [Printed in the August, 1921, issue of THE JOURNAL]

THE DISCUSSION

RUSSELL HOOPES:—In the destruction of the road, what is the relative effect of different amounts of unsprung weight of the wheels and the axle of vehicles?

A. T. GOLDBECK:—There is a somewhat decreased impact on the road surface due to light unsprung weight as compared with heavy unsprung weight. This is, however, not the most important effect; it is overshadowed by variations in the tire equipment. We may get variations in impact due to tire equipment of as much as 200 per cent. The variation in impact due to unsprung weight does not nearly approach that.

MR. BACHMAN:—Motor trucks have been developed to meet road conditions as they were found. As they have existed with regard to surface, grading and the like, road conditions have been such as to require a certain type of construction for the movement of certain loads, which represents weight of a certain quantity. Given a different type of road construction, with a material reduction in the gradient and an improvement in the surface, an entirely different form of construction that will give another definite quantity of weight for the vehicle can undoubtedly be used. The ultimate purpose of transportation is not to create a vehicle so much as it is to move merchandise. The ideal vehicle would be one that was entirely negative and did not exist; one could move merchandise by utilizing some invisible force. How we are to solve this proposition is what Mr. Goldbeck is asking, and I think the Society also is vitally interested. Road builders have the problem of constructing roads for vehicles that have been created for various conditions and will under improved conditions be capable, from power and structural standpoints, of carrying considerably greater loads than they are able to carry under present conditions. On the other hand, the builder of vehicles is forced to take into consideration the road conditions that exist at present as regards the weight and power of the vehicle.

One of the big factors in the fuel problem is the road problem. There are remarkable differences in the ton-mileage per gallon of fuel with different road conditions. I have driven the same truck over two different roads about 30 miles long in the vicinity of our factory; one has a gradient close to 18 per cent on one section; the other is an improved highway of excellent construction and has a gradient of probably not over 6 or 7 per cent. The latter is not a low grade from a railroad standpoint and probably not an impossible grade from a highway standpoint. The difference in operation, in ton-miles per gallon, over those two types of road is very remarkable. We must consider the whole highway problem from both the highway and the vehicle standpoints and the highway and the automotive engineers must work together.

PROFESSOR WILSON:—Is it a fact that, while the use of pneumatic tires instead of solid tires reduces impact on the road surface, it does not give the distribution of load necessary to prevent a breaking down of the sub-structure, and that the latter can be prevented only by using more wheels per vehicle?

MR. GOLDBECK:—The pneumatic tire is practicable only up to a certain size and is capable of carrying only a certain maximum load. It does not distribute the load sufficiently over the road surface; its area of distribution is not greatly different from that of a solid tire, from the standpoint of the structural design of the road. So, although the pneumatic tire does greatly reduce the impact and would do a tremendous amount of good if we used it on the large sizes of present and future trucks, it is necessary to at least consider the matter of using more wheels per vehicle. I advocate that we seriously consider the possibility of doing that.

H. W. SLAUSON:—Has Mr. Goldbeck made any tests regarding the length or the type of spring suspension used on the trucks and the effect on the impact? He has stated that the amount of unsprung weight makes relatively little difference. Do the type and design of the spring make as little difference?

MR. GOLDBECK:—We have made no tests regarding the spring suspension. That probably will be taken up this year.

MR. SPERRY:—It is a fact that a watt-hour meter on a street car shows very little difference in current consumption whether the car runs on a track of heavy grade or on a level track. We have just heard that gasoline consumption is very much higher on highways having steep grades. If that is true, it seems to me to be the business of engineers who have to do with the gearing of trucks and automobiles to determine whether all of that difference is not due to the gears. When a truck moves on a good pavement having grades, there should be little difference in effect between it and the same pavement without grades. The gear situation is not essentially different from that of a street car, and the power consumption should obey the same laws.

R. P. LAY:—Many of the present highways are constructed under factors similar to those governing the construction of the old-style dirt roads. As a result, the

vehicle must be slowed down to negotiate the turns and bridges safely. Why should not new roads be laid out in straight lines as nearly as possible? When a curve is necessary, it should have a large radius, and bridges should be made wide enough that two vehicles can pass each other on them. The suggestion is made that the Government buy additional land on the inside of road curves, cut down trees and remove other obstructions to vision, so that car drivers can see whether the road beyond is clear and keep their cars at high speed.

MR. MOSKOVICS:—I wish to call attention to the fact those parts of the United States that have the best roads experienced the best automotive business in the past year. In California and the Eastern States, where practically each community has good intercommunicating roads, the business was less affected by the industrial depression than in any other part of the country. One of the first States to feel the automobile depression was Iowa, where roads are not developed as they are in these other sections. I know of nothing more effective that an automotive engineer can do to increase the eventual prosperity of the automotive industry than to cooperate with the road builders to secure more good roads throughout this country.

A railroad engineer does not stop at the science of building a locomotive; he interests himself in and has much to do with the rails and the roadbed. Why should not the automotive engineer act correspondingly in his field? He is in duty bound to his industry, to the institution he represents and to himself, to do everything he can to enlarge the sphere of use of automotive equipment and to make that use less costly and more convenient. No one would argue that anything would enhance more the convenience of motoring and the lowering of upkeep costs than really good roads.

Automotive engineers have done a considerable amount of talking on this subject; let them reduce this to a real practical basis. The Government of the United States, represented by Mr. Goldbeck, has asked for our cooperation. Let us go more than half way. I am going to make a formal motion to that effect, but I strongly urge that the subject be not dropped with the mere formality of passing a resolution, because I believe it is one of the most important things before the entire industry. It merits the best attention of the technical men of the industry. Therefore, Mr. Chairman, I move that it is the sense of the members assembled at this meeting that a committee should be appointed to cooperate with the proper highway officials at Washington by lending every aid of this Society, from a technical standpoint in the design of those products that are made by the manufacturers represented by the members, to assist those officials in their work. [The motion was carried unanimously.]

MR. GOLDBECK:—I am glad that this resolution of cooperation has been passed. I desire your cooperation with highway engineers in particular. I would like to see accomplished the getting together of those who have to do with the motor truck and those who have to do with the highway. Highway engineers are sometimes apt to design highways with the idea of getting mileage for a certain amount of money. That is wrong in principle. It neglects the fact that the highways have to carry a certain definite amount and maximum weight of traffic. In the past the motor-truck designer has not had in mind particularly the effect the truck has on the highways and the reduction of the ultimate cost of transportation, which is the thing I wish to see accomplished. I think that highway engineers have not understood automotive engineers, and that the reverse also is true. Let us solve our difficulties together.

EDUCATION FOR HIGHWAY TRANSPORT

BY CHARLES J. TILDEN

THE author discusses the kind of college education that should be offered to those who expect to become engaged in highway transportation by motor truck, with reference to organization, regulation and operation on a large scale. Stating that the main factors of such an education fall naturally into the three divisions of the highway, the vehicle and the business, these are considered with regard to what topics might be presented profitably to college students under these respective heads, the subjects and the factors that govern their desirability being commented upon in general terms.

The main principle which should be borne in mind in educating men for the motor-transport business and the main value of such an education lie in the intellectual development and ability to analyze critically, which give the student mastery over new situations as they arise, and ready adaptability to the needs of any given business situation. [Printed in the September, 1921, issue of THE JOURNAL]

THE DISCUSSION

ALFRED REEVES: — Professor Tilden, who has been granted a year's leave of absence from Yale, is director of the Highway and Highway Transport Education Committee, which is a volunteer committee supported by contributions and working with the Government installing highway-engineering courses in the colleges of the country to insure an even better grade of men to handle highway problems in the future than we have had in the past. It seems appropriate to follow Professor Tilden's paper by some facts relative to this road problem. Appropriations of some $624,000,000 are now available in this Country for road improvement; so it is important that we train men to expend this money in the most efficient way. The Townsend Bill now before Congress calls for $100,000,000, matching dollar for dollar the money appropriated by the States, and providing that the money shall be expended on interstate roads and not on unrelated sections of roads. The latter plan has wasted money and effort in the past.

Roy D. Chapin, who is the chairman of the National Automobile Chamber of Commerce Highways Committee, fought last year to prevent the passage of a bill at Washington that called for $100,000,000 for good roads. It passed the House and was defeated in the Senate. President Harding wanted to know why the automobile industry should object to such an appropriation for roads. When he found that our opposition was based on our feeling that the bill did not properly conserve the taxpayers' money, our position before Congress and our appeals were substantially advanced. President Harding in his last message called for more improved roads throughout the Country, and primarily for their maintenance after they are constructed. He declared that the motor car had become an indispensable instrument in our industrial, social and political life.

I understand that Mr. Kruttschnitt, of the Southern Pacific Railroad, assailed the motor truck on the ground

that it is cutting into the railroad business; that we had highways built for us with the taxpayers' money, whereas the railroads had to buy their own rights of way. The fact is that many of the railroads obtained their rights of way for practically nothing, with miles of additional land donated to them. Moreover, when a railroad builds a right of way, it has the exclusive use of it. When the public builds a highway, it is open to the world. The rivers and harbors are dredged by the Federal Government, but they are available for use by the ships of all the world for the benefit of all.

We find commodities moving over the four main channels of transportation, the highways, rivers or waterways, railroads and interurban lines. The position of the automotive industry, which I believe is sound, is that all transportation interests have a common ground and a common interest, that each has an individual function to perform, and that their manner of performing it will bring its own reward. In other words, insofar as the motor car or motor truck is a more meritorious medium of transportation than the railroad or the interurban trolley line, it will get its share of the business. The entire world is crying for more efficient methods of transport. The Society is to be congratulated on the big dominating part it is taking in helping to meet this urgent demand on the part of the public.

SAFETY FUEL-TANKS FOR AIRCRAFT

THE British Air Ministry has stated that the possibility of aircraft catching fire in the air has been almost entirely eliminated by care in design and inspection, but that such precaution is not sufficient to protect, in every case, an airplane from the results of a crash. One of the main objects to be attained is to insure that in a heavy landing or a crash the fuel-tanks on an aircraft, even though seriously damaged, will withstand the shock to which they may be subjected without either bursting or leaking. Accordingly, with the object of obtaining for use in service and commercial aircraft safety tanks that will fulfill these conditions and at the same time withstand the effects of enemy action by machine-gun and shell-fire a competition for safety fuel-tanks has been arranged to commence on Dec. 1, 1921.

Prizes to the extent of £2,000 will be awarded to the entrants of the tanks that are considered best. The first prize will be £1,400, the second £400 and the third £200. The competition will be held at a place to be decided upon later. Any competitor may enter several different types of tank, but two specimens of each type must be supplied for preliminary tests and four for the final tests. Entries, which should be addressed to the Secretary, Air Ministry, Kingsway, London, W.C.2., marked "Safety Fuel Tank Competition," will be received until Nov. 7, 1921. These should be made on a form that will be supplied on request. The control of the competition will be in the hands of a committee appointed by the Air Council. Its decision as to awards will be final and without appeal.

Tanks should be constructed so as to prevent as far as possible leakage or ignition of fuel when subjected to stresses similar to those to which the tank would be subjected in an aircraft crash and to machine-gun fire using incendiary armor-piercing or explosive ammunition. Equal importance is attached to these requirements.

A tank is to be capable of being fitted within a space of 2 x 2 x 2½ ft. and to have a capacity that must be within 5 per cent of 30 gal., but any shape of tank will be accepted for competition. All the necessary fittings to enable the tank to be mounted in a structure for testing purposes must be supplied by the competitor. The maximum weight, complete with fittings, which would be justified only by very exceptional qualities, should not exceed 1.75 lb. per gal. of capacity. Tanks exceeding this figure will not be disqualified, but great importance will be attached to low weight. In all cases the tank is to be complete with the necessary fittings to enable it to perform its functions of supplying fuel to a fixed point. In the case of tanks designed to incorporate leak detectors and similar instruments and devices, these will be fitted in such a manner as to show their efficiency under test, and will be included in the weight. In every case there must be at least one filler and also unions for supply and delivery connections, one of the latter at the top, the other at the bottom of the tank.

The relative importance of other characteristics of the tanks will be considered in the following order:

Light weight
Durability under service conditions in the absence of any accident[1]
Indifference to extremes of temperature
Adaptability of design to large capacities
Simplicity of construction
Adaptability of design to various shapes
Accessibility of fittings
Cost of production

All tanks will be subjected to preliminary trials. The three best types will be selected by the judges for a final trial. For the preliminary tests both tanks submitted will be subjected to a crashing test of the following nature:

Each tank will be mounted in a wooden structure and located behind a concrete body formed to represent an engine. The tank will be released down a wire ropeway approximately 100 ft. high, arranged so that the structure will strike the ground at an angle of not less than 45 deg. from the horizontal and be free to turn over. This will insure as far as possible the conditions prevailing in a typical aircraft crash. The tank will contain 22 gal. of gasoline which will be supplied by the Air Ministry.

In the four tanks supplied for the final tests minor modifications of the original design may be made, provided the judges have previously decided that the modification is one of detail and not fundamental principle. The tanks will be required to undergo a crashing test similar to that in the preliminary stages and also a firing test in which they will be subjected to machine-gun fire with ammunition capable of penetrating the ordinary type of mild-steel fuel-tank and leaving small entry and large exit-holes when the tank is struck below the fuel level, and exploding and igniting the fuel either on contact or after penetration. A series of bursts of five rounds each will be fired at a range of 50 yd., the tank being examined after each burst. The angle of fire will be at the discretion of the judges.

At any time during the competition the judges may impose such other tests as they may desire to demonstrate the relative merits of competing tanks. There will be an interval of at least eight weeks between the preliminary and the final tests.

[1] In the case of scout aircraft the stress due to acceleration may amount to three or four times that due to gravity.

ACTIVITIES OF THE SECTIONS

Sections Calendar

BUFFALO
(Secretary—George H. Pettit, 1569 Jefferson Street, Buffalo)

CLEVELAND
(Secretary—E. W. Weaver, 5103 Euclid Avenue, Cleveland)

DAYTON
(Secretary—R. B. May, Dayton Engineering Laboratories, Dayton)
Oct. 4—All-Metal Design of Airplanes by I. M. Laddon

DETROIT
(Assistant Secretary—Mrs. B. Brede, 1361 Book Building, Detroit)

INDIANA
(Secretary—B. F. Kelly, Weidely Motors Co., Indianapolis)
Oct. 7—Chassis Design by C. E. Jeffers

METROPOLITAN
(Secretary—F. E. McKone, 347 Madison Avenue, New York City)
Oct. 7—Aberdeen Proving Ground

MID-WEST
(Secretary—L. S. Sheldrick, 910 South Michigan Avenue, Chicago)
Oct. 7—Dinner at Chicago Automobile Club
Oct. 28—Technical Meeting

MINNEAPOLIS
(Secretary—C. T. Stevens, 13 South Ninth Street, Minneapolis)
Oct. 5—Manifold Design and Fuels

NEW ENGLAND
(Secretary—H. E. Morton, B. F. Sturtevant Co., Hyde Park, Boston)
Oct. 14—Address by C. H. Metz and Discussion of Massachusetts Headlight Law

PENNSYLVANIA
(Secretary—T. F. Cullen, Chilton, Co., Market and 49th Streets, Philadelphia)
Oct. 7—Aberdeen Proving Ground

WASHINGTON
(Treasurer and Acting Secretary—C. H. Young, 210 Riggs Building, Washington)
Oct. 7—Aberdeen Proving Ground

THE visit of the Society and of the Metropolitan, Pennsylvania and Washington Sections to Aberdeen Proving Ground on Oct. 7 in response to General Williams' invitation to be present to witness the tests and demonstrations to be given on that date, will constitute one of the most important meetings of the season. At the last Summer Meeting it seemed impracticable to stage an exhibit of ordnance materiel due to the expense involved. Because of the interest of our members, however, it was believed that a visit to the Proving Ground would be of greater benefit, since it is possible to conduct demonstrations there on a larger scale than elsewhere. The program given on another page indicates the scope of the tests. Arrangements have been made for special cars leaving New York on Thursday night, Oct. 6, and extra accommodations have also been provided from Washington and Philadelphia on the morning of Oct. 7. Those expecting to attend should notify the Commanding Officer, Aberdeen Proving Ground, Md., at the earliest possible moment, enclosing a check for $3 to cover the expense of the luncheon and the dinner that will be provided by an outside caterer.

SECTION MEETINGS

Most of the Sections have submitted complete or partial plans for their fall and winter programs.

The Dayton Section has reported the following schedule: Oct. 4, All-Metal Design of Airplanes by I. M. Laddon; Dec. 6, Lubrication by Dr. H. C. Dickinson, and March 7, Airplane Cooling Systems by Capt. Lorenzo L. Snow.

Detroit held its first fall meeting on Sept. 30, with an address by Dr. Dickinson. Tentative dates throughout the rest of the year have been fixed as Oct. 21, Nov. 18, Dec. 23, Jan. 24, March 24 and April 28. The contemplated subjects are Fuel Research, Aeronautics, Passenger-Car Bodies and Production Economies.

Indiana has called its first meeting for Oct. 7 at which C. E. Jeffers will give a paper on Chassis Design.

The Metropolitan Section reviewed the fuel papers of the Summer Meeting on Sept. 15. H. L. Horning led the discussion. On Oct. 7 this Section will join with the Society in its trip to the Aberdeen Proving Grounds. There will be a paper on Chassis Lubrication at the November meeting, including a discussion of approved methods and recent developments; a meeting on the Commercial Development of the Airplane in December; and, throughout the remainder of the year, papers on Factors Affecting the Design of Rear Axles for Trucks and Transmission Power Losses. In addition to these meetings, it is planned to hold a joint meeting with the New England Section at some southern New England point, which probably will take the form of a visit to a plant.

The Mid-West Section will hold an informal dinner-meeting on Friday, Oct. 7, at the Chicago Automobile Club, to which visitors are invited particularly. Plans for the winter program will be discussed at this meeting and a special effort made to increase the membership. It is expected that the first technical session will occur on Oct. 28. The Section proposes to hold a series of meetings throughout the fall and winter on the Fundamental Theories Underlying the Operation of Internal-Combustion Engines, including thermodynamic laws, principles of carburetion, advanced combustion phenomena and a study of the heat losses in an engine.

The members of the Minneapolis Section held their first fall gathering in the form of an inspection tour of the State Fair on Sept. 8. At meetings throughout the year there will be considered such subjects as Manifold Design, Fuels, Tractor Wheels and Traction, Steam Power for Farm Tractors, Road-Building Machinery and Engineering, Power Cultivators and Tools, Engine-to-Ground Power Absorption in Tractors and Tractor Publicity and Demonstrations.

The New England Section had an outdoor meeting in Worcester on Sept. 17. The October meeting will consist of an address by C. H. Metz, and a discussion of the Massachusetts Headlight Law. An ignition meeting will be held on Nov. 11, in Springfield; a meeting on aircraft development in December, probably at Worcester; a visit to the Stanley plant in Newton, together with a paper by E. H. Delling, chief engineer of the company, on Jan. 13; and an isolated lighting plant meeting at Boston or Worcester, with a paper by Mr. Wilkins of the H. C. Dodge Co. A spring meeting will be devoted to the discussion of the business aspects of the automotive industry. A joint meeting with the Metropolitan Section will conclude the Section program for the year.

The Pennsylvania Section spent the afternoon of Sept. 22 at Torresdale Golf Club, having dinner at Morrelton Inn. An evening session, the occasion of a short review of some of the important Summer Meeting papers, followed the dinner. President Beecroft was the guest of the evening. The Section will visit the Aberdeen Proving Grounds on Oct. 7. On No. 22 there will be a fuel and diesel-engine meeting. H. L. Horning and A. K. Brumbaugh will be the speakers. An aviation meeting is scheduled for Dec. 22, and it is probable that an inspection trip will be made to the Naval Aircraft Factory at the League Island Navy Yard. In Janury, 1922 it is intended to have a continuation of the discussion evoked by the Society's Annual Meeting papers. It is hoped to have a number of the authors of these papers in attendance. Current Business Conditions will receive attention at the meeting on Feb. 23; Batteries and Electrical Equipment on March 23; and Commercial Motor Transportation on April 27.

Current Standardization Work

ALTHOUGH the summer months have in past years generally been a period of inactivity for the Standards Committee members, the work of the last few months has resulted in great progress, several Division and Subdivision meetings having been held and reports submitted. A large amount of information has been obtained by the Standards Department for the use of Subcommittee members desiring to base preliminary recommendations on present engineering practice.

Division Meetings

At the meeting of the Parts and Fittings Division held on Sept. 12 in New York City several reports were accepted and will be submitted for action at the Standards Committee Meeting on Jan. 10, 1922. A meeting of the Engine Division was held on Sept. 20 in the rooms of the Old Colony Club, Hotel Cleveland, Cleveland. Several important subjects were discussed, including mufflers, engine numbers, engine testing-forms, fan belts and pulleys, engine torque, oil-pumps and water-pumps.

A meeting of the Transmission Division was held on Sept. 21 at Cleveland. A report on clutch facings, submitted by A. C. Bryan, was discussed. Other subjects acted upon at this meeting were gear-tooth strength formulas, transmission drive for speedometers, transmission tire-pump mountings and clutch-bearing oiling mechanisms.

The Passenger-Car Body Division members met on Sept. 23 at the Hotel Tuller in Detroit. Reports on body nomenclature, door-handle squares, door-fit clearances, nickel-plating, plate glass and top-irons were submitted for consideration.

A meeting of the Iron and Steel Division, held on Sept. 26 at Buffalo, indicated that a complete revision of the present iron and steel specifications and notes and instructions would be ready for Society action in January. On Sept. 27 the members of the Non-Ferrous Metals Division also met in Buffalo. Subdivision reports recommending revisions of and additions to the present non-ferrous metal alloy specifications were acted upon.

Aeronautical Safety Code

An organization meeting of the Aeronautic Safety Code Sectional Committee sponsored by the Society and the Bureau of Standards was held on Sept. 2 at New York City. H. M. Crane, chairman of the Aeronautic Division of the Society Standards Committee, was elected chairman, J. S. Ames of the National Advisory Committee for Aeronautics, was named vice-chairman and M. G. Lloyd of the Bureau of Standards, designated as secretary.

The chairman was empowered to appoint subcommittees, to facilitate the work of the Sectional Committee, one of which is to compile unbiased information giving the actual reasons for all airplane accidents in the future. It is expected that this information will be of great value in drawing up the safety code.

Body Top-Irons

A Subdivision report on top-irons has been submitted to the members of the Passenger-Car Body Division by O. H. Clark. It was based on a survey of present-day practice, representing a large variety of types and sizes, the great majority of which, however, specified a 7/16-in.—14 U. S. Standard thread. This thread was therefore specified for the top-irons recommended and should meet with general approval.

The top-iron types recommended cover all general requirements. The over-the-rail type top-iron is identical with a top-iron put out by a large manufacturer except that the length of the stud and the thread has been definitely specified. The through-the-rail type front top-iron also recommended can be used through the rail by body builders who do not wish to provide for the removal of the top-irons in case a permanent top is used. This type is superior to the separate through-the-rail type front and rear top-iron recommended in the report inasmuch as it is not necessary to counterbore such large holes through the rail for the top-iron sockets, which would naturally weaken the top rail.

Airplane Tachometer Drive

It is thought by some members that the S. A. E. Recommended Practice for Airplane Tachometer Drive should be revised by changing the diameter of the tachometer driving-shaft, page C76, S. A. E. Handbook, from 0.152 plus or minus 0.001 in. to 0.187 plus or minus 0.001 in. and changing the drill size and the hole diameter for the tachometer driving-shaft given on page C77 from Drill No. 20 (0.161 plus or minus 0.002 in.) to Drill No. 11 (0.191 plus or minus 0.002 in.). It has been stated that the dimensions of the tachometer shaft connection at the engine are not of suitable proportions to insure freedom from trouble, especially in the operation of the centrifugal type of tachometer that turns faster than indicated speed. The suggestions have been referred to the Powerplant Subdivision of the Aeronautic Division.

Carbureter Flanges

It was tentatively proposed at a recent meeting of the Engine Division to change the flange dimensions of the ½-in. carbureter size, page A8, S. A. E. Handbook, to conform with the flange dimensions for the ⅝-in. size and to change the dimensions for the ¾-in. size to conform with the dimensions for the ⅞-in. size, the actual inside diameters remaining the same. This revision is considered desirable because it would permit makers to purchase castings to better advantage, as four sizes of flange could be made from two sizes of casting and two sizes of gasket would be eliminated. The Division also plans to formulate a standard for motorcycle carbureter-flange dimensions.

Clutch Facings

The following report on clutch facings was submitted by A. C. Bryan at the Transmission Division meeting held Sept. 21:

SINGLE PLATE CLUTCHES

The majority of single-plate clutches are made in three sizes, 8, 10 and 12 in. In Table 1 are listed the single-plate clutch-facing sizes produced at present by leading companies.

TABLE 1—PRESENT CLUTCH-FACING PRACTICE

Size of Clutch, in.	8	10	12
Borg & Beck			
Inside Diameter, in.	5⅜	6¾	8¼
Outside Diameter, in.	7⅞	9⅞	11⅞
Detroit Gear & Machine			
Inside Diameter, in	5⅜	6⅞	...
Outside Diameter, in.	7⅞	9⅞	...
Hoosier			
Inside Diameter, in.	5½	6⅞	8$\frac{5}{16}$
Outside Diameter, in.	7⅞	9⅞	11$\frac{13}{16}$

In view of the fact that most single-plate clutches for passenger cars and trucks are similar in design and are housed by flywheels bored 8, 10 and 12 in., respectively, standard inside and outside diameters are proposed as shown in Table 2, as these sizes will fit present clutches without any change in the design of the clutch parts.

TABLE 2—PROPOSED CLUTCH-FACING PRACTICE

Size of Clutch, in.	8	10	12
Woven-Fabric Split Facings			
Inside Diameter, in.	5⅜	6¾	8¼
Outside Diameter, in	7⅞	9⅞	11⅞
Molded Ring Facings			
Inside Diameter, in.	5⅜	6¾	8¼
Outside Diameter, in.	7$\frac{31}{32}$	9$\frac{31}{32}$	11$\frac{31}{32}$
Thickness, in.	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{5}{32}$

When woven-fabric facings are used in single-piate clutches, they work better with $\frac{1}{16}$-in. clearance all around, but molded facings must fit within $\frac{1}{64}$-in. clearance all around or they will cause a distinct noise when the clutch is released. This is due to the fact that facings in the majority of single-plate clutches are not fastened to the discs and will throw about when released, the hard molded facing causing the noise. Two sizes are therefore suggested, one for the molded facing and one for the woven-fabrc facing, as given in Table 2. The question of thickness will probably cause some discussion as both $\frac{1}{8}$ and $\frac{5}{32}$-in. thicknesses are used.

MULTIPLE-DISC CLUTCHES

A great number of multiple-disc clutches on the market are so varied in design as to make the standardizing of facing sizes for them somewhat more difficult.

In selecting sizes for facings in a multiple-disc clutch design, there are two factors to consider

(1) The inside diameter of the facing must be large enough to go over the driven hub. The hub size is largely governed by the spring construction used

(2) The outside diameter of the facing must be small enough to fit in the driving drum or spider

The S. A. E. Standard for Flywheel Housings, page A1, S. A. E. HANDBOOK, specifies the dimensions for attaching the driving drum or spider of a multiple-disc clutch to the flywheel. There is an advantage in having the mean radius of the facing as large as possible as the driving power of the clutch is directly proportional to this. I have ascertained from a number of layouts that a 8⅝-in. outside diameter facing is about the largest that can be used with an internal-gear or key-driving drum and allow the use of a socket-wrench to tighten the cap-screws holding the drum to the flywheel, using the dimensions specified in the S. A. E. Standard.

It is a direct advantage from the standpoint of cost to use as few facings and discs as possible in a multiple-disc clutch, but in so doing the spring pressure must be increased to take care of the torque and the width of the facing made such that the unit pressure on the facing is not excessive. Another advantage is the fact that the travel necessary to release the clutch is more or less proportional to the number of discs, so that the high spring-pressure necessary can be provided easily by a linkage without excessive travel of the pedal.

The Raybestos Co., after much experimenting, recommends a unit pressure of 20 lb. per sq. in. on molded facing and a coefficient of friction of 0.16, which it has found will give good service with a large factor of safety. S. O. White has recommended a facing size of 8⅝-in. outside diameter with a 1¼-in. face and an inside diameter of 6⅛ in. The area of this size of facing is 29 sq. in. and with it a five-plate clutch, capable of transmitting the torque of the heaviest engines used in passenger-car or truck work, can be designed by use of the following formula:

$$T = (n \times S \times r \times f) / 12 \qquad (1)$$

where

f = the coefficient of friction
n = the number of facings
r = the mean radius = 3.69 in.
S = the spring pressure
T = the torque in pound-feet

Twenty pounds per square inch unit pressure with 29 sq. in. of surface requires a 580-lb. spring.

Substituting in formula (1) we have

$$T = (10 \times 580 \times 3.69 \times 0.16) / 12 = 285 \text{ lb.-ft.} \qquad (2)$$

This provides for a much more powerful engine than is ordinarily used in the heaviest trucks or passenger cars. In actual practice, in all probability, the figures given will not be realized due to design and inaccuracies in machining and assembling; but it seems that this five-plate clutch would actually take care of the engines ordinarily used in the heaviest passenger cars or trucks so far as facings are concerned.

Another facing size that should be adopted is 8⅝-in. outside diameter and 6⅝-in. inside diameter with a 1-in. face. This would have a mean radius of 3.812 in.

$$T = (8 \times 350 \times 3.81 \times 0.16) / 12 = 144 \text{ lb.-ft.} \qquad (3)$$

From the above it is evident that a four-plate clutch with a 350-lb. spring, which is commonly used, will handle an engine ordinarily used in the lighter passenger cars and speed trucks.

Another point is that by using this size of facing the driven hub can be carried over the flywheel bolts, saving considerable length in the clutch, the transmission main drive-gear and the transmission housing, which is an item in cost. Care must be taken in clutch designs using large facings not to have too much revolving weight in the driven member as this might tend to cause trouble in gear-shifting.

It is desirable at times to use smaller-diameter facings than those mentioned above, the size depending on the spring construction and the length available for the number of facings needed. There are a number of satisfactory disc clutches on the market having facings with an inside diameter of from 5¾ to 6¼ in. and an outside diameter of from 7¾ to $8\frac{7}{16}$ in. Within this range the 6-in. inside diameter and 8-in. outside diameter seem to be the most popular and work out very satisfactorily. It may, however, be advisable to have more than one size within this range. This point will need serious consideration.

Summing up, I recommend that the sizes of clutch facing shown in Table 3 be adopted as S. A. E. Standard.

TABLE 3—PROPOSED S. A. E. STANDARD CLUTCH-FACING SIZES

Size of Clutch, in.	8	10	12
Single-Plate			
Inside Diameter, in.	5⅜	6¾	8¼
Outside Diameter (Fabric), in.	7⅞	9⅞	$11\frac{7}{8}$
Outside Diameter (Molded), in.	$7\frac{31}{32}$	$9\frac{31}{32}$	$11\frac{31}{32}$
Multiple-Disc			
Inside Diameter, in.	6⅛	6⅝	6
Outside Diameter, in.	8⅝	8⅝	8
Thickness	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{5}{32}$

CONNECTING-RODS

A report, consisting of curves, has been submitted by G. M. Ozias, chairman of the Stationary Engine Subdivision on Connecting-Rods, covering the following connecting-rod relationships:

Connecting-rod lengths against strokes, in inches
Crankpin diameters against bores, in inches
Piston-pin diameters against bores, in inches
Crankpin diameters against crankpin lengths, in inches
Projected areas of the piston-end connecting-rod bearing, in square inches, against bores, in inches
Projected areas of the crank-end connecting-rod bearing, in square inches, against bores, in inches

The curves were plotted from data obtained from 16 different makes of single-cylinder stationary engine and will be discussed and acted upon at the next meeting of the Stationary Engine Division.

GREASE-CUPS

It has been argued that the Society should standardize a definite series of grease-cup sizes for use on automotive vehicles. Information is being obtained as to present practice.

DOOR-FIT CLEARANCES

As standard door-fit clearances would be of great assistance to body engineers, the Passenger-Car Body Division has tentatively recommended the following clearances:

Location	Clearance, in.
Hinge Side	⅛
Lock Side	3/16
Bottom	7/32
Top	⅛
Jamb	3/16
Bead	3/32

These clearances are for all types of body and are measured from wood-to-wood or metal-to-metal before painting. The top clearance does not apply to open bodies.

Engine Torques

It has been stated by a member of the Electrical Equipment Division that in the application of starting and lighting equipment an S. A. E. Standard recommending a given starting torque and a given cranking speed for an engine of a given piston displacement would be helpful to both the car builders and the makers of starting and lighting equipment. The torque and speed would, of course, have to be different for engines with different numbers of cylinders as well as for engines of different types.

Lamp Glasses

It has been suggested that the present S. A. E. Standard for lamp glasses, page B6, S. A. E. Handbook, be extended to specify the dimensions given in Fig. 1 of the locking lugs of the head-lamp glass rim, to prevent the glass from turning in the lamp.

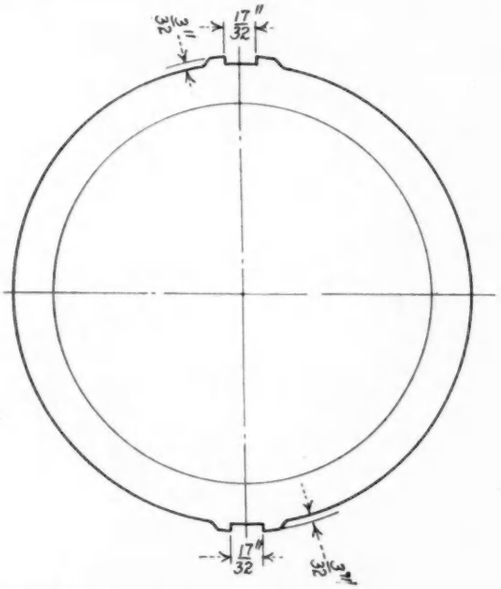

Fig. 1—Proposed Arrangement of Head-Lamp Glass Rim To Prevent the Glass from Turning in the Rim

Tail-Lamps

The standardization of tail-lamp overall dimensions and mounting screws has been suggested in view of the great variety of mountings used at the present time that might easily be reduced to one standard design, acceptable to both lamp and automobile manufacturers. The dimensions tentatively recommended, given in Fig. 2, are in accord with present practice. The advantages claimed to result from the use of this construction are

(1) The tail-lamps can be mounted on either the right or the left side of the license-plate, thus eliminating the necessity of making right and left lamps, which is the practice at present
(2) The socket coming out at the center of the back of the lamp makes the wiring very simple
(3) The holes in the bracket on the automobile can be drilled on the vertical line, thus allowing the lamp to be mounted either above or below the license bracket
(4) As the bulb is in the exact center of the lens, even illumination of the lamp glass, regardless of the length of the bulb socket or the diameter of the tail-lamp shell, is obtainable

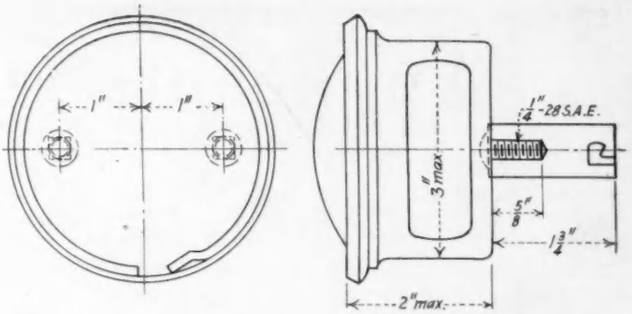

Fig. 2—Tentative Recommendation for a Standardization of Tail-Lamp Overall Dimensions and Mounting Screws

Flywheel Housings

The present S. A. E. Standard for Flywheel Housings, pages A1 and A2, S. A. E. Handbook, specifies that the minimum diameter of the clearance space for crankshaft flywheel-bolt heads shall be 6⅛ in. and the minimum depth ⅝ in. As these are the actual dimensions and should, in the opinion of a member of the Engine Division, be increased to allow a clearance of ⅛ in. on the diameter and a clearance of 1/16 in. over the nuts, the standard will be reopened at an early date.

Shaft and Housing Fits and Tolerances for Ball Bearings

The Ball and Roller Bearing Division has under consideration a revision of the Information on shaft and housing fits and tolerances for ball bearings published on page C33 of the S. A. E. Handbook. This general information, which was accepted for publication in March, 1921, has been criticized to the effect that the housing fits are too close for commercial machine-work. This question will be thoroughly discussed at the next meeting of the Division.

RADIO-CONTROLLED AUTOMOBILE DEVELOPED BY THE AIR SERVICE

THE most interesting part of the radio-controlled automobile developed by the engineering division of the Air Service at Dayton, Ohio, is the selector that is the heart of the entire control system. Various combinations of dots and dashes are sent out by a specially constructed transmitter, each combination calling for the accomplishment of a certain operation of the control apparatus. It is the function of this selector to decode these various combinations of dots and dashes and to close the circuits to the desired controls. So delicately is this selector constructed and so rapidly will it operate, that it is possible to put into operation any one of 12 distinct controls in a period of less than 1 sec. The car has been controlled equally well from an airplane and a ground transmitting station. It is about 8 ft. long and runs on three pneumatic-tired wheels at a speed of from 4 to 10 m. p. h. It is said that it can be steered easily by radio along a narrow roadway.

The possibility of radio control and its application to wartime problems are almost without number. Radio control can be supplied to any mechanical apparatus that moves, whether it be in the air, on the ground, on the surface of the water or beneath the water.—Air Service News Letter.

Applicants *for* Membership

The applications for membership received between Aug. 22 and Sept. 16, 1921, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

BARTLETT, PERCY H., chief tester, Sinclair Refining Co., *Oak Park, Ill.*

BEEGLE, CLIFFORD H., salesman, Union Drawn Steel Co., *Detroit.*

BUSHNELL, SHERMAN W., automotive engineer, Sherman W. Bushnell, *Seattle, Wash.*

CASSILLY, MERLE E., tractor repairman, Rock Island Arsenal, *Rock Island, Ill.*

CHENOWETH, OPIE, field man, Peoples Loan & Trust Co., *Winchester, Ind.*

CLERK, DUGALD, SIR, civil engineer, National Gas Engine Co., Ltd., *Ashton-under-Lyne, England.*

CONNOR, P. J., mechanic tool salesman, E. L. Easley Machinery Co., 555 West Washington Boulevard, *Chicago.*

EVANS, CLARK, student, University of Michigan, *Ann Arbor, Mich.*

FLAGE, JOHN E., superintendent of manufacturing and assistant chief engineer, Ray Battery Co., *Ypsilanti, Mich.*

GRABOW, FRED C., designer, Shaw-Enochs Tractor Co., *Minneapolis.*

GRANDSTAFF, BEN F., manager repair parts department, Munger Automobile Co., *Dallas, Tex.*

HURD, RALPH H., engineer, Libby & Huls, *Chicago.*

KERSHAW, LEONARD F., draftsman, Fox Motor Car Co., 7th and Grange streets, *Philadelphia.*

KOERBER, ARTHUR W., draftsman, O. E. Szekely Engineering Co., *Moline, Ill.*

KRAUSE, EMIL F. W., expert and sales organizer, Utility Battery Co., *Chicago.*

KUBACKA, JOSEPH E., body engineer, Victor Pagé Motors Corporation, *New York City.*

KULICKE, F. W., sales engineer, Atwater Kent Mfg. Co., *Philadelphia.*

LA HATTE, MILNER T., division manager and associate engineer, Selden Truck Corporation, *Rochester, N. Y.*

LINCOLN, JOSEPH B., mechanical engineer, Naval Engineering Experiment Station, *Annapolis, Md.*

MERRITT, RALPH V., general foreman, Brewster & Co., Inc., *Long Island City, N. Y.*

MOHORI, TERUO, Japanese Government student in agriculture and commerce, 13816 Argus Avenue, *Cleveland.*

NEELANS, HAROLD G., student, University of Michigan, *Ann Arbor Mich.*

PARR, C. H., engineer, Hart-Parr Co., *Charles City, Iowa.*

POMY, HERMAN J., factory representative, Self Seating Valve Co., *Chicago.*

SCHAGELIN, EDWARD G., service superintendent, Nash Sales Corporation, 440 Mercer Street, *Jersey City, N. J.*

SENIOR, THOMAS K., assistant chief engineer, Cleveland Automobile Co., *Cleveland.*

SHEAFF, HOWARD, draftsman, Wittemann-Lewis Aircraft Co., *Hasbrouck Heights, N. J.*

SHEEHAN, DANIEL J., student, University of Michigan, *Ann Arbor, Mich.*

UNDERWOOD, ARTHUR J., student, University of Michigan, *Ann Arbor, Mich.*

WHEELER, RICHARD F., buyer, Stevens-Duryea, Inc., *Springfield, Mass.*

WING, WILFORD W., service engineer, Frigidaire Corporation, *Dayton, Ohio.*

Applicants *Qualified*

The following applicants have qualified for admission to the Society between Aug. 10 and Sept. 9, 1921. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

APPERSON, EDGAR L. (M) president, Apperson Bros. Automobile Co., *Kokomo, Ind.*

BIRMINGHAM, C. J. (A) service manager, Locomobile Co., 16 West 61st Street, *New York City.*

BROCKETT, ASHLEY H. (M) instructor in automotive engineering, Carnegie Institute of Technology, *Pittsburgh,* (mail) 1835 Bluff Street.

DOYLE, JOSEPH A. (A) sales, service, Stromberg Motor Devices Co., 68 East 25th Street, *Chicago.*

GEE, HAROLD W. (J) assistant superintendent, gas works, Georgia Railway & Power Co., Atlanta, Ga., (mail) 529 North Church Street, *Decatur, Ga.*

GOSSLING, W. E. (M) storage battery engineer, Prest-O-Lite Co., Inc., 30 East 42nd Street, *New York City.*

GIBSON, ALLEN W. (A) special representative, Prest-O-Lite Co., Inc., New York City (mail) 132 23rd Street, *Elmhurst, N. Y.*

HARMON, C. O. (A) sales, Cleveland Experimental Laboratories Co., *Cleveland,* (mail) 1747 Bryn Mawr Avenue, East.

HOOVEN, ALBERT M. (A) secretary and treasurer, Meteor Motors Corporation, Philadelphia, (mail) 25 North Wycombe Avenue, *Lansdowne, Pa.*

INSLEY, ROBERT (J) aeronautical mechanical engineer, engineering division, Air Service, McCook Field, *Dayton, Ohio,* (mail) Powerplant Laboratory.

KELLY, RAYMOND J. KING (A) automobile race driver, designer, builder and aviator, J. Alex. Sloan, *Chicago,* (mail) 5958 Washington Boulevard.

LEE, ROY E. (M) chief draftsman, Russell Motor Axle Co., *Detroit,* (mail) 1998 Leslie Avenue.

LOVE, HORACE (A) H. H. Franklin Mfg. Co., *Syracuse, N. Y.*

MARTIN, P. B. (A) manager, service stores, Westcott Motor Car Co., *Springfield, Ohio,* (mail) 126 East Cassilly Street.

MURRAY, ROBERT ROY (A) mechanical superintendent, Provincial Highways Board, *Halifax, N. S., Canada,* (mail) 4 Carleton Street.

ORTEIG, JULES P. (A) president, Orteig Motor Co., *New York City,* (mail) 317 West 99th Street.

PATRICK, FRANK E. (A) sales representative, Acme Storage Battery Corporation, Poughkeepsie, N. Y., (mail) 144 Lakeland Avenue, *Cleveland.*

PIERCE, J. OTIS (A) sales manager, Brown-Lipe Gear Co., *Syracuse, N. Y.* (mail) 1117 West Fayette Street.

PROSPERI, A. G. (A) sales engineer, Oakland Motor Car Co., *Atlanta, Ga.,* (mail) Wyndham Courts.

SHRUM, A. T. (J) chief draftsman, Walker Vehicle Co., State and 87th Streets, *Chicago.*

STROHM, GROVER E. (A) sales engineer, Prest-O-Lite Co., Inc., New York City, (mail) 541 East Larned Street, *Detroit.*

TIPTON, WILLIAM D. (J) 1618 St. Paul Street, *Baltimore.*

VALTIER, FRANK (M) industrial engineer, Milburn Wagon Co., Monroe Street, *Toledo.*

WEINBERG, SAMUEL (E S) automobile engineering student, draftsman, 135 Stockton Street, *Brooklyn, N. Y.*

WILLETT, E. F. (A) manufacturers agent, National Gauge & Equipment Co., La Crosse, Wis., (mail) 4835 Woodward Avenue, *Detroit.*